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16. ABSTRACT

The Fabric Filter Inspection and Evaluation Manual was prepared to assist Federal and State enforcement groups in the following decisionmaking areas: estimation of filter system (baghouse) compliance with emissions regulations; appraisal of filter system adequacy for a specific control application; and evaluation of operating and maintenance procedures in the light of recommended practices. In Chapter 2, basic concepts pertaining to fabric filtration, particle behavior, and particle size measurements are highlighted so that inspection personnel can evaluate facilities for which no precedence has been established. Given prior experience or the need for immediate action, however, the Manual user may go directly to Chapter 3 where important day-to-day aspects of filter system operation are presented along with emphasis on what may go wrong and what remedial measures should be undertaken. Different types and procedures for baghouse inspections are described in Chapter 4; e.g., compliance determination, startup, troubleshooting, general preventive maintenance, or special investigations, where the specific information sought and the sequence of the inspection process may vary.

A sample report format is presented that indicates the areas of concern for emissions compliance determinations. Supporting material are provided in several appendices including a comprehensive glossary of terms used in fabric filtration technology.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	
Air Filters	Stationary Sources	
Compliance Determinations	Fabric Filters	
Filter Maintenance	Mechanical Shaking	
Filter Inspections	Pulse Jet Air	
Woven Fabrics	Reverse Flow Air	
Felts		

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February 1984

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CHAPTER I

INTRODUCTION

1.1 PURPOSE OF MANUAL

Fabric filtration (1-8) is expected to play an increasingly important role as the preferred control technology for reducing particulate emissions from utility, industrial, and other sources to the strict compliance levels now set by Federal, State, or local agencies. However, compliance with Federal Standards of Performance for New Stationary Sources or other appropriate standards set forth in SIP rules and regulations may be difficult to attain or consistently maintain unless it is assured that:

- fabric filtration is indeed the best choice (or at least an acceptable alternative) for controlling a specific particulate emission, and
- the fabric filter is operated and maintained in accordance with accepted engineering practice.

The purpose of this Fabric Filter Inspection Manual is to enable Federal, State, or local field inspection personnel to make the correct field observations and to ask the right questions so that they can provide the enforcement office with the following information:

- Does the filter system appear to be in compliance based on observed operating parameters and performance characteristics?
- Is the system being applied and operated in accordance with the design purposes and specifications?
- Do the plant filter system inspection and maintenance procedures (and those for applicable process equipment) appear likely to guarantee continued compliance with emission regulations?

The Fabric Filter Inspection Manual is designed to answer these questions by familiarizing technically trained enforcement personnel with the practical aspects of designing, operating, and maintaining fabric filter systems. On the other hand, basic filtration concepts are presented to enable inspection personnel to evaluate certain facilities for which no precedence has been established. Considerable emphasis, however, is directed to the day-to-day aspects of filter system operation with respect to what may go wrong and what corrective measures should be taken to prevent or minimize system malfunctions.

1.2 MANUAL ORGANIZATION

1.2.1 Special Role of Chapter II

The organization and technical content of the manual is intended to provide enforcement personnel with the tools to conduct effective field inspections of fabric filter systems. The judgements that must be made as to whether compliance with emission regulations has or can be attained depend upon how well the inspector understands not only the practical aspects of fabric filter operation but also the underlying concepts controlling the filtration process.

Given the need for rapid decision making, the user can go immediately to Chapter III and subsequent chapters for technical guidance without risk of serious errors of judgement, particularly so if the individual has had prior training and experience in filtration technology. Conversely, if the manual user has had only limited filtration experience and the evaluation of a fabric filtration operation permits some lead time, his ability to analyze system behavior and to assess its potential for emissions compliance will be greatly enhanced by a careful reading of Chapter II, "How Fabric Filters Work". In the long term, we strongly advocate that inspection personnel develop a solid qualitative understanding of the basic concepts presented in Chapter II. These include a review of fundamental particle collection mechanisms, collection theory, gas and particle properties relevant to fabric filter design and operation, choice of performance criteria, and selection of fabrics and collector types.

Because of the importance of knowing the size and concentration of the particles to be collected, a section of Chapter II has been devoted to the sampling and measuring techniques recommended for field aerosol evaluation. Although the technical coverage is necessarily brief, the highlighting of key sizing and sampling concepts supported by extensive references will help the field inspector avoid many common mistakes.

1.2.2 The Working Sections of the Manual

The practical "hands on" aspects of inspecting fabric filtration facilities for compliance purposes are described in Chapters III and IV and related appendices in the working sections of the Manual.

Chapter III, Typical Baghouse Problems/Corrective Actions, addresses specific operational problems and their respective solutions that concern the baghouse user. In addition to a general discussion of typical problems encountered with baghouse components, ancillary equipment, and processes being controlled, actual field (user) experience in these same areas is presented in this Chapter.

Chapter IV, Baghouse Inspections, Types, and Procedures, presents information on the various kinds of inspections performed by users, vendors, and air pollution agency personnel. Depending upon the required type of inspection; i.e., compliance determination, startup, troubleshooting, general preventive maintenance, or special investigations, different information may be sought or the sequence of the inspection process may change. In addition to a discussion of the above items, a suggested inspection report format has been provided.

Additionally, several appendices are provided to aid air pollution engineers in their performance of fabric filter surveys or inspections. Appendix A is a glossary of the more common terms used for describing aerosol systems and sampling procedures while Appendix B provides supplementary information on size measurement techniques. Appendix C lists the terminology associated with baghouses, baghouse operation, and fabric properties. Additional examples of available baghouse designs and ancillary equipment are presented in Appendix D and U.S. suppliers of baghouses, based on 1982-1983 listings, are indicated in Appendix E. Appendix F highlights the key features of a predictive model that is intended to facilitate the design and evaluation of fabric filter systems.

The information contained in this manual should provide the reader with a representative data base that will enable more detailed and meaningful inspections of fabric filter systems. At the same time, a thorough appreciation of field problems should encourage cooperation between the control agency and the filter user in seeking to correct emission problems. It is also pointed out that fabric filtration may not necessarily be the optimum choice for emissions control when highly humid, corrosive, or very high temperature gas streams require cleaning. The reader is directed to alternative control technologies such as wet scrubbing or electrostatic precipitation(9-14).

CHAPTER II

HOW FABRIC FILTERS WORK

2.1 BACKGROUND

Fabric filters represent but one of several filter types used to remove particulate materials from waste or process gas streams (1-8). Although fabric filter applications and related maintenance constitute the sole subject of this manual, field enforcement personnel should be aware of the other filter types and their normal applications because they are often encountered at the same plants where fabric filters are used. Progressing from the least to the most efficient, the four basic filter types (2,3,7,8) are as follows:

- Fiber mats or screens (15-18) composed of straight or curled fiber filaments or ribbons, 35 to 150 μm diameter, randomly packed in highly porous (~98 to 99 percent) layers and ranging in depth from 1/2 to 4 inches. Structural stability is provided by supporting screens or adhesive bonding (~5 to 10 percent by weight) and dust adhesive properties are usually enhanced by sticky oil coatings. The primary application of such filters is to remove coarse (~10-20 μm) particles from the ambient air or from process air with solids concentrations less than 500 $\mu g/m^3$ (a) to prevent the dispersal of staining, sootlike particles, pollen grains, and gritty material likely to damage internal combustion engines, or (b) to extend the service life of costly, ultrahigh efficiency HEPA* filters used to collect highly toxic particles such as radioactive, chemical, and biological materials. Mat or screen units are commonly described as roughing, precleaning, furnace, or "throwaway" filters, wherein all except those composed of heavy-duty metal frames and metal screens are thrown away once they become plugged. Steam cleaning followed by re-oiling (dipped or sprayed) are used to recycle heavy metal screen or fiber units used, for example, to prefilter diesel engine combustion air or public building supply air. The efficiency of this filter class may be as high as 90 percent for >10 μm particles, provided that the fiber medium is uniformly dispersed and lubricated.

- High efficiency fiber mats (19-21) fabricated in pleated configurations and composed of randomly packed, relatively fine (5 to 10 μm) adhesive-bonded fiber, usually glass. The primary role of such filters, described as high efficiency precleaners, is to reduce approaching dust concentrations in the 1 μm size range by a factor of ten or so to extend the life of costly, HEPA-type filters or, when used alone, to provide high quality air to critical occupied areas where soiling or bacterial presence must be minimized.

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*HEPA - High Efficiency Particulate Arrester

- Fabric filters (1-8) consisting of woven or felted media used in the form of bags, tubes, and sometimes envelopes to provide high efficiency cleaning of high particulate loadings, 2 to 20 grams/m^3. The utilization of the fabric and the overall operation of industrial filter systems embody the same principles seen in home vacuum cleaners except for the provision for cleaning, without interruption of gas flow, and the capability to function in difficult working environments involving high temperatures, corrosive atmospheres, and high dust loadings. The key factor differentiating fabric filters from the other filter types discussed in this section is that the high efficiency filtration is performed by the dust layer that accumulates on the fabric surface. The role of the fabric is to provide a stable support or substrate for this dust layer that will (a) permit a uniform, unbroken dust layer to develop, and (b) withstand the rigors of the working environment during filtration and, in particular, during any cleaning process that involves repeated stressing and flexure of the fabric. In both appearance and structure, filtration fabrics are similar and often the same as the woven or felted products used for clothing, protective coverings, substrates for plastic sheeting, decorative purposes, etc. Details with respect to weave, yarns, thread counts, and special surface treatments will be discussed in a later section. Operating temperatures, resistance to chemical attack, and method of cleaning determine the source and chemical classification of the fibers making up the filter. Typical operating efficiencies are usually well in excess of 99 percent, and often greater than 99.9+ percent, provided that the system has been properly applied, installed, and maintained. This manual will deal only with the operation and maintenance of fabric filter systems.

- Ultrahigh efficiency particulate arresters (3,6,8,22,23) (HEPA), consisting of tightly pleated, high-efficiency mineral fiber (0.5 to 1.5 μm diameter) papers providing gas handling capacities of 500 to 1,000 ft^3/min for 2 ft. x 2 ft. cells ranging from 6 to 12 inches, respectively, in depth. Refractory edge seals and fibers allow high temperature operation (up to 1000°C) for low (100 μg/m^3) concentrations, with efficiencies in excess of 99.95 percent against 0.25 μm diameter particles. Major applications for HEPA filters are the collection of radioactive and/or biological particles, although they are also used extensively for clean room operations to prevent particle fouling of delicate optical systems or solid state electrical circuitry.

2.2 MECHANICS OF DUST FILTRATION

2.2.1 Basic Concepts (1,2,8,24-31)

Particle capture by any single collector, regardless of shape, depends upon a combination of particle, collector, and gas stream properties and the relative velocity between particle and collector. Single collector in the above context refers to an individual fiber, droplet, or any other geometric shape with which a particle makes contact. In most instances, the motion of the gas stream past fixed or moving obstacles (collecting fibers, granules, or liquid droplets) determines the relative velocity, although thermal, diffusional, electrical, and vibrational forces also contribute to velocity effects.

The interrelationships among the major variables responsible for particle collection are reviewed briefly in this section. The most important step in analyzing any filtration system is to determine what causes a specified particle to be brought into contact with the filter fiber(s) neglecting for the moment any subsequent particle dislodgement by gas stream re-entrainment. First, with respect to any filter system, the carrier gas stream is diverted by the fibers obstructing the flow such that it assumes a winding path.

2.2.2 Particle Capture by Direct Interception (1,8,22,24-26)

If the particle trajectories are always coincident with the direction of the gas streamlines regardless of changes in gas stream direction, only those particles whose boundaries extend beyond the supporting streamline will make physical contact with the collector. Although such contacts are not always irreversible due to frequent particle dislodgement and re-entrainment by the gas stream, irreversible capture is assumed for present analytical purposes. This collection mechanism, which is defined as direct interception, plays a major role in filtration when the particle and fiber diameters are very similar and where the fiber proximity precludes direct penetration of most particles. Figure 1 illustrates how particles are captured by direct interception, a process that is independent of the physical properties of a particle (except for its location). A rough estimate of the magnitude of the interception effect is provided by the interception efficiency, n_{DI},

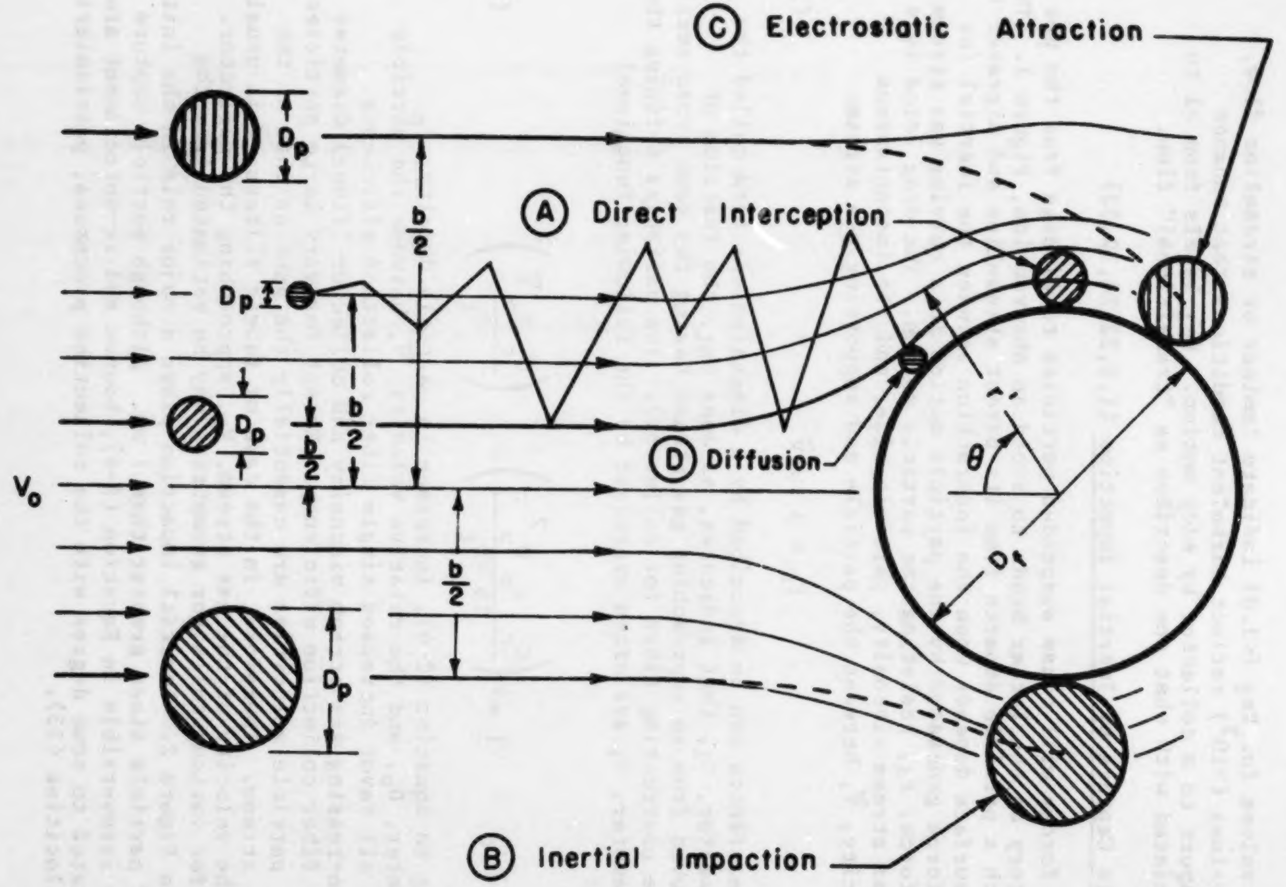
$$n_{DI} = (2 - \ln Re_f)^{-1} \left(\frac{D_p}{D_f}\right)^2, \qquad (2\text{-}1)$$

that indicates the fraction of particles removed from a gas stream tube having the same cross-sectional area as that of the collector fiber (25).

Equation (2-1) shows that the interception effect increases as the fiber or collector diameter, D_f, decreases relative to that of the airborne particle, D_p. Hence, one should expect better performance for the individually dispersed fibers of a felt fabric (~15 to 30 μm in diameter) than for the tightly entwined fibers making up the yarns whose overall dimensions in a woven fabric may range from 200 to 500 m.

Because the stagnant gas film or boundary layer surrounding a fiber or a granule increases significantly as the flow velocity decreases, the fluid streamlines assume more divergent paths to circumvent any obstacle in the stream (22). The net effect is to make it more difficult for a suspended particle to contact a potential collector. Use of the fiber Reynolds number, Re_f, criterion provides an approximate measure of the boundary effect.

$$Re_f = D_f \tilde{V} \rho_g / \mu, \text{ (consistent units)} \qquad (2\text{-}2)$$


C Electrostatic Attraction
A Direct Interception
D Diffusion
B Inertial Impaction
D_p
D_p
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$\frac{b}{2}$
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$\frac{b}{2}$
$\frac{b}{2}$
V_o
θ
D_f

Figure 1. Streamlines and particle trajectories approaching filter element.

where D_f = fiber diameter
$\tilde{V}$ = relative velocity between particle and fiber
ρ_g = gas density
μ = gas viscosity

Very low values for Re_f (<1.0) indicate laminar or streamline flow, whereas high values (>10^3) reflect turbulent conditions that enhance particle transport to a collector by eddy motion. Re_f levels from >1 to 10^3 are associated with what one describes as "transitional" flow.

2.2.3 Particle Capture by Inertial Impaction (1,8,22,24,32,33)

Inertial forces will cause suspended particles to diverge from the gas stream trajectory as the latter bends to avoid an obstruction, Figure 1. The extent to which a particle departs from its parent streamline and migrates to a collecting surface depends upon the interaction between the inertial (or centrifugal) force generated by the particle motion in a curving gas stream and the drag force, F_d, resisting the particle motion. The drag force is a function of gas stream viscosity, particle size, and the instantaneous relative velocity, $\tilde{V}$, between the particle and supporting gas stream.

$$F_d = 3\,\pi \mu d \tilde{V} \tag{2-3}$$

The above effects can be described by a dimensionless term called the impaction parameter, η_I, that indicates, as does η_{DI}, the fraction of particles removed from an approaching gas stream having the same cross section as that of the obstructing fiber (or collector). The variables defining the impaction parameter, η_I are often expressed by the following functional relationships:

$$\eta_I = \phi \left(\frac{C_c \; \rho_p \; D_p^{\,2} \; \tilde{V}}{18\, \mu D_f} \right) = \left(\frac{C_c \; V_t \; \tilde{V}}{D_f} \right) \tag{2-4}$$

According to Equation (2-4), increases in particle density, ρ_p, particle diameter, D_p, and the relative velocity, $\tilde{V}$, between the particle and collector all favor increased single fiber collection efficiency. Conversely, increasing gas stream viscosity and collector (fiber) diameter reduce single fiber collection efficiency. Except for very large particles, >100 μm, most particle velocities are essentially the same as that of the conveying gas stream. Therefore, in the case of fabric filters, $\tilde{V}$ is usually the same as the velocity of the gas stream, V_g, approaching the collector. Values of η_I for various collector geometries may be estimated from the graph shown in Figure 2. Inertial impaction plays a major role in the initial filtration of particle sizes greater than 1 μm. Although particle capture is assumed to be irreversible in Equation (2-4), bounce and re-entrainment are always associated to some degree with the collection processes, particularly so at high velocities (33).

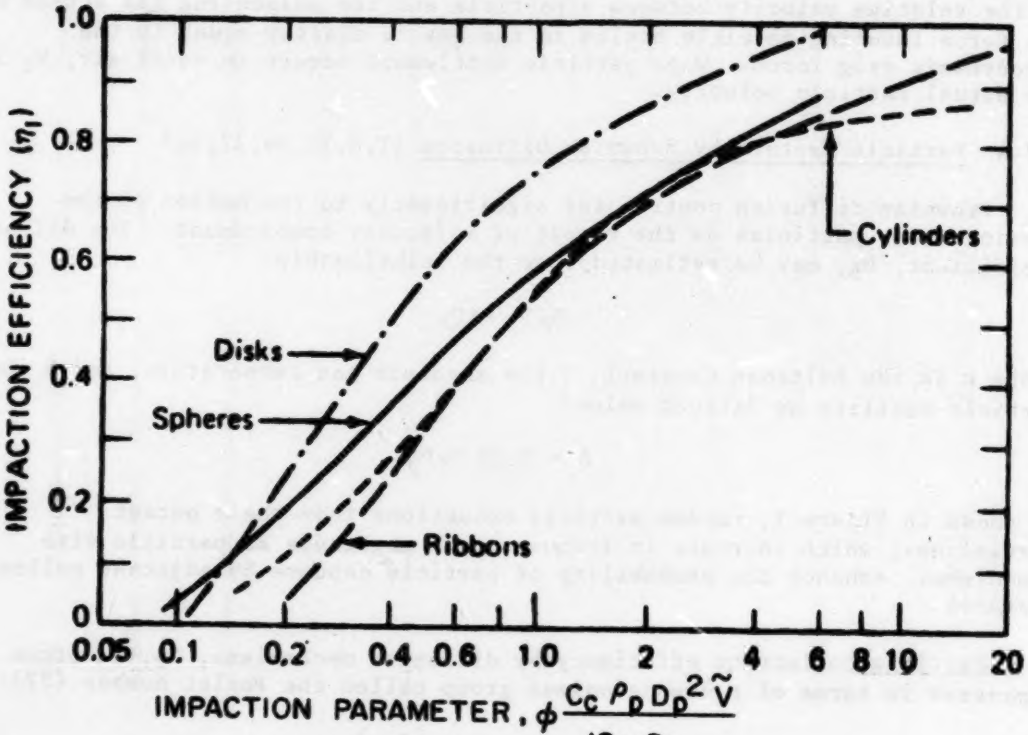


Figure 2. Impaction efficiencies for cylinders, spheres, ribbons, and disks.

When dealing with particles 1 μm or less in diameter, the term C_c in Equation (2-4), the Cunningham-Millikan correction (22,24-26), may become very large and hence very important in predicting particle collection. This correction takes into account the fact that particles appreciably smaller than the mean free path of a gas (λ) ~0.6 μm at ambient temperatures, can literally "slip" through the gas with more ease than larger particles. For rough calculating purposes, C_c may be taken as 1.0 for diameters of 1 μm or larger. It may be estimated from the empirical relationship:

$$C_c = 1 + 1.7\ (\lambda/D_p) \tag{2-5}$$

The term V_t refers to the terminal settling velocity that is also equal to the relative velocity between a particle and its suspending gas stream when the force inducing particle motion in the gas is exactly equal to the aerodynamic drag force. When particle settlement occurs in still air, V_t is the actual particle velocity.

2.2.4 Particle Capture by Brownian Diffusion (1,8,22,24,32,34)

Brownian diffusion contributes significantly to the motion of the submicrometer particles as the result of molecular bombardment. The diffusion coefficient, D_B, may be estimated from the relationship:

$$D_B = kBT, \tag{2-6}$$

where k is the Boltzman constant, T the absolute gas temperature, and B the particle mobility as defined below:

$$B = C_c/3\ \pi\mu D_p \tag{2-7}$$

As shown in Figure 1, random particle excursions from their parent streamlines, which increase in frequency and magnitude as particle size diminishes, enhance the probability of particle capture by adjacent collection surfaces.

Particle collection efficiency by diffusion mechanisms, η_D, is often expressed in terms of a dimensionless group called the Peclet number (22):

$$\eta_D = k\left(P_e\right)^{-2/3} = k\left(\frac{D_B}{D_T V}\right)^{2/3}, \tag{2-8}$$

where $P_e = D_T V/D_B$ and k is a term that varies from 6.2 to 2.4 over the range of 0.7 to 0.99 for fabric or granule bed porosity. Equation (2-8) indicates that particle collection can be expected to increase with increasing diffusion coefficient, D_B, decreasing collector or target diameter, D_T, and decreasing gas stream velocity, V. Because relatively low filtration velocities are used in fabric filtration and the fiber sizes instrumental in particle capture as well as the filter pore dimensions may be quite small (~10 to 20 μm), diffusional mechanisms can play an important role during the earlier stage of fabric filtration until a superficial dust layer has formed. Diffusional capture is most important for particles of submicrometer size.

2.2.5 Particle Capture by Electrostatic Mechanisms (1,8,22,24-26)

Although electrostatic charge plays a major role in particle collection by electrostatic precipitators, it is usually difficult to determine how much effect the electrostatic charge on particles and/or fibers has upon capture during filtration. In most field applications, it is a common occurrence to find that a certain fraction of the dust bears an essentially unipolar charge, with either positive or negative charges predominating except for very low particle concentrations. Usually, most particles bear less than 10 percent of their maximum possible charge. Theory suggests that charge phenomena may augment the performance of a filter system (Figure 1) under the following conditions: a charged fiber and an uncharged particle, particles and fibers charged to opposite polarities, and a charged particle and an uncharged fiber (35-40). In routine fabric filter applications with dust loadings in the range of 0.1 g/m^3 to 20 g/m^3, the above electrostatic mechanisms are mainly of academic interest with respect to enhancing collection efficiency.

In the case of low-to-moderate efficiency roughing filters, collection efficiency may be enhanced by impressing an electric field across a filter composed of low dielectric, glass or mineral fibers (35,37,39). Local distortion or convergence of the field in the immediate vicinity of the dielectric fibers causes uncharged or charged particles of either polarity to migrate toward the fibers. This process, which is sometimes described as dielectrophoresis, is an adjunct to collection only when particulate loadings are near the ambient level, 25 to 250 μg/m^3. At high concentrations, its contribution to particle collection will be insignificant in comparison to the effects of the collection mechanisms discussed earlier in this section.

The concept of precharging dust particles prior to filtration as a means of increasing gas handling capacity without the matching penalty of high pressure loss is now under investigation at the prototype level (41). In contrast to a naturally charged aerosol, this process generates high charge levels of single polarity. The benefits of this approach may be significant provided that cost problems associated with construction, operation, and maintenance of the charging system are overcome. It appears that this process reduces the pressure loss through the dust layer by causing the latter to deposit at a higher porosity due to repulsion of similarly charged particles (38).

For most practical filtration applications, the presence of natural electrical charges may usually be ignored except for certain dusts, e.g. powdered resins that are characterized by dense wall deposits and extreme stickiness relative to dislodgement from fabrics. Such systems will be discussed under the special problem category.

2.2.6 Particle Collection by Direct Sieving (1-3,22,28,29,31,42)

Collection by sieving implies that the openings, channels, or separation distances between filter fibers, yarns, or granules are less than the characteristic dimensions of the approaching particles. Hence, the collector may be considered as a screen whose mesh size either prevents or allows particle penetration. Ordinarily, the fiber separation distances in most fabrics are too large to allow for direct sieving of any but the very large particles (~20 to 50 μm) present in the gas stream. Thus, during the first minute or so of filtration, direct interception and diffusion, with augmentation from inertial impaction and electrostatic effects, play important roles in causing the particle bridging that must precede the formation of a superficial dust layer (22,43). Bridging describes the process wherein the sequential deposition of particles, first on fibers and then upon previously deposited particles, leads to formation of chain-like agglomerates (34). At dust concentrations in excess of 0.5 g/m^3, these chains rapidly interlace with adjoining members to form the supporting bridge for dust cake development.

It is the dust cake that ultimately constitutes the true filter, and the process by which particles are collected can be best described as sieving because particle proximity in the dust cake per se reduces the size of the pores or channels to the same order as those of the approaching particles (2, 22,28,42,44). Despite the fact that dust cake porosity usually exceeds that for the bulk dust removed from baghouse hopper (~60 to ~90 percent versus 40 to ~60 percent for the bagged dust), the distance between particles is sufficiently close to make direct sieving the predominant capture mechanism. In the above case, the porosity, or void fraction, ε, can be related to discrete particle density, ρ_p, and cake bulk density $\bar{\rho}$ by the following expression:

$$\varepsilon = 1 - (\bar{\rho}/\rho_p) \tag{2-9}$$

The effectiveness of the sieving operating is frequently masked, however, by defects in the dust cake surface, cracks or unblocked pores, tears in the fabric, temporary absence of a dust cake that is a normal part of the fabric cleaning process, and a nearly constant seepage of agglomerated particles through the fabric substrate as a result of the mechanical action induced by cleaning and aerodynamic drag forces (31,42,45,46). The degree to which the above factors contribute to the total filter effluent is related to a combination of dust and fabric properties, method of cleaning, and filter system maintenance procedures. Except for will-weave glass fabrics frequently used for coal fly ash filtration, there is no existing theory or even an empirical approach that allows for reliable estimation of dust penetration resulting from the above factors.

It has been observed that unavoidable pinhole leaks with glass fabrics are responsible for 95 to >99 percent (masswise) of the total filter effluent. Because only the coarser particles (>20 μm range) are removed from the gas that passes through the pinhole leaks, the particle size properties of the effluent are very similar to those of the dust approaching the filter, even though the overall collection efficiency may well exceed 99.9 percent (31,42).

2.2.7 Particle Capture by Gravitational Forces (1-8,22)

Gravitational forces can usually be discounted as a contributor to particle capture within the dust and fabric structure of the filter per se. Only in the case of very deep bed granular or fiber filters (~ several feet) and at low velocities (<0.5 ft/min) may the impact of gravity settlement be seen, and then only for systems where the inlet dust concentrations are at ambient levels of ~25 to 250 μg/m^3. On the other hand, gravity settlement with augmentation by inertial forces may lead to significant losses of large (>20 μm) particles in lengthy horizontal ducts and in breechings, transition sections, or collector inlets where increased gas stream cross section leads to greatly reduced flow velocities. The possibility of particle separation by gravity forces should be taken into account when dust sampling for estimates of mass concentration and particle size is performed well upstream of the fabric filter (or other control devices) (31,42,46,47). The extent to which gravitational effects may be expected to influence particle separations may be estimated by computing particle terminal velocity, V_t. The latter term describes the constant rate of particle fall in still air when the resistance to motion presented by the air (or suspending gas) equals the local gravitational force.

$$V_t = \frac{C_c(\rho_p - \rho_g) g D_p^2}{18 \mu_f} \qquad (2\text{-}10)$$

For many applications, the Cunningham-Millikan correction, C_c, is approximately 1.0 in situations where V_t is of concern and, for most aerosol systems, the gas or fluid density, ρ_f, can be neglected because it is roughly 500 to 1,000 times less than that for the particulate materials. As a frame of reference, a 61 m diameter silica particle will settle at about 1 ft/sec (30.5 cm/sec) in air at standard conditions (760 mm Hg, 20°C). Given a reduced air velocity of 10 ft/sec in a 50 ft long breeching section, all 61 m particles within 2 ft of the bottom of the ducting will fall out. Detailed analyses of settling phenomena, including the more complex process of settling behavior in turbulent gas streams, are treated extensively in the literature (1,8,22,24,25).

2.2.8 Physical Processes Enhancing Particle Capture

2.2.8.1 Agglomeration (1,22,24-26)--

Agglomeration (or coagulation) is the process by which airborne particulate materials collide and adhere to form larger particles. When liquid droplets collide, the process is called coalescence. The mechanisms and forces promoting these collisions (and particle growth) are the results of Brownian motion and electrical, aerodynamic, gravitational, sonic, or magnetic effects.

Electrical and sonic forces, however, have had limited applications as means of enhancing particle contacts, whereas naturally occurring thermal or Brownian diffusion and the aerodynamic mixing engendered by gas stream turbulence are major contributors to agglomeration. The benefit of agglomeration is that it increases particle size, which in turn, means increased probability of particle capture by the direct interception and inertial impaction processes described in Equations (2-1) and (2-4). It should also be recalled that Brownian motion and turbulent diffusion increase the probability of particle contacts with the collection surface (fiber, granule) or collector wall in the case of baffle or cyclonic devices.

The rate of thermal agglomeration (coagulation) may be estimated by the comparatively simple equation,

$$n_t = n_o/(1 + K'n_o t,) \qquad (2\text{-}11)$$

where n_t and n_o refer to the particle concentration at time t and time zero, respectively, and K' to the Smoluchowski coagulation constant.

$$K' = 3 \times 10^{-10}\ \mathrm{cm^3/sec\ particle}$$

$$n_t,\ n_o = \mathrm{particle/cm^3}$$

$$t = \mathrm{sec}$$

The important role played by agglomeration is demonstrated by the average reduction in particle number concentration when initial concentrations are high. For example, freshly generated fume at an initial concentration level of 10^{10} particles/cm^3 would undergo a nearly tenfold decrease in concentration in less than three seconds. If the initial mean size by number were roughly 0.1 µm, the average mass per agglomerate would increase tenfold and the impaction parameter, η_I, about 3.5 times, assuming a 50 percent porosity for the agglomerates. Hence, the potential for increased particle capture by filter systems is greatly enhanced while the pressure loss per unit mass of dust deposit would be lowered significantly because of the more porous structure. Although K' has been treated as a constant, it does in fact depend upon gas temperature, gas viscosity, and C_c, the Cunningham-Millikan correction. However, over the diameter range 0.1 to 1.0 µm, the magnitude of K' shows less than a threefold reduction (8.57 to 2.99 x 10^{-10}).

2.2.8.2 Condensation and Evaporation (1,22,24-26)--

Although neither evaporation nor condensation play direct roles in most filtration applications, there are two situations where these processes must be considered. The first relates to the treatment of hot, humid gases, such as, typical fossil fuel combustion effluents, wherein reduction of temperatures below the vapor dew point will lead to liquid condensation on all particle and system surfaces below the dew point temperature. This behavior, which constitutes a decided advantage in the case of liquid scrubbing systems because of the resultant growth in particle size, creates a serious pressure loss problem with a dry filtration system. The adverse effects may range from that of a sticky dust deposit that requires a high energy expenditure to clean the filtration surfaces to the extreme condition of a blinded filtering surface impervious to gas flow. The above problems are avoided by maintaining system gas stream temperatures at all points and at all times well above the dew point of any condensable constituent.

The second process, that of evaporation, promises to be an important pre-preparation or conditioning step in dry scrubbing systems where absorbable gases such as sulfur oxides are first captured by transfer to liquid droplets containing reactive alkali materials followed by flash drying such that the resultant aerosol consists solely of dry solids. Subsequent filtration, again at above dew point temperatures, affords very high particulate removal and up to 90 percent SO_x collection. In the above case, process effectiveness centers upon regulation of the evaporation or drying process. Although no detailed discussion of condensation or evaporation phenomena is called for in this manual, it is important to recognize the key factors involved in these mass transfer operations.

The following equation provides rough estimates of droplet evaporation rates, $-dm/dt$, for diameters as small as 2 µm.

$$-\frac{dm}{dt} = 4\pi D_v m_2 (C_o - C) r \tag{2-12}$$

where D_v = diffusion coefficient for evaporating or condensing molecules

m_2 = mass of diffusing molecule

C_o = vapor molecular concentration at droplet surface

C = vapor molecular concentration in surrounding gas stream

r = droplet radius

When the molecular concentration (or partial pressure) of the condensable vapor is less in the surrounding gas stream than that at the droplet surface, the droplet will decrease in size (evaporation), whereas a reversal in gradient leads to condensate and droplet growth. The rate of size change also increases with droplet size and the process is greatly accelerated in a turbulent atmosphere where molecular transfer from or to the droplet may increase by orders of magnitude.

2.3 FABRIC FILTRATION VERSUS SINGLE FIBER COLLECTION

2.3.1 Single Fiber Collection Efficiency and Amount of Fiber (1,2,8,24,31)

In the preceding sections, the major particle capture mechanisms have been identified with respect to single particle-single collector interactions. Several equations were given which, based upon theoretical considerations, provide relative measures of particle collectability for various combinations of particle, fluid (gas), and collector (fiber and granule) parameters. It is important to note, however, that the computed collection efficiency for a single particle-single collector system may be an extremely poor performance indicator for a real fabric filter.

Two extreme conditions may be cited to demonstrate this point. In the first instance, the calculated collection efficiency for a specified particle-fiber combination is very high (~0.9). Unfortunately, a single fiber will capture only those particles that appear within a cross sectional area representing 90 percent of the projected fiber cross section. This means that all particles beyond this boundary will never contact the fiber. Thus, if the fiber projected area represents but 1 percent of the total cross section through which the dust-laden gas passes, the maximum possible filtration efficiency cannot exceed 0.9 percent.

The other extreme is represented by the system in which single particle-single fiber efficiencies are low (~5 percent), but where a large number of such fibers are dispersed within the cross section through which the dusty gas must pass. Given sufficient fiber projected area, the efficiency for the fiber system composed of bulk, woven, or felted fibers may then approach 100 percent. In the following discussion, simple analytical procedures are described for estimating the collection efficiency of a typical woven fabric filter.

2.3.2 Typical Fabric Filtration Process (1-3, 28,29)

A schematic representation of woven glass fabric during various stages of filtration, Figure 3, shows that initial particle collection occurs on the free or bulk fibers that project into the spaces between the yarns (31,42). With increased service, the free fiber region rapidly bridges over so that subsequent filtration is accomplished by the overlying dust layer. Note that the role of the fibers tightly entwined within the yarns is merely to provide strong support for the free fibers (and the dust deposit) as well as the strength needed to withstand the long term wear and tear of repeated cleanings. At the inception of filtration, particles retained by the fibers are captured by a combination of processes. Diffusion and/or direct interception account for collection of the finer particles, while inertial impaction is responsible for the collection of larger particles. However, once a substantial surface dust layer has formed, direct sieving becomes the predominant capture mechanism for all regions where the dust layer is unbroken (free of cracks, pinholes, or other defects).

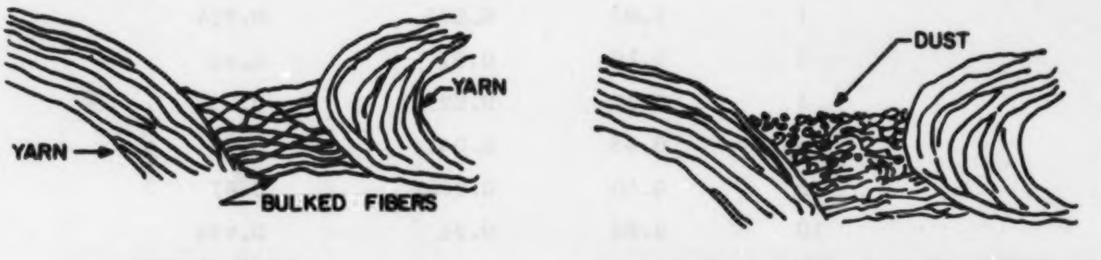
2.3.2.1 Initial Fiber Filtration Phase--

Based upon theoretical considerations, the initial efficiency, E_{fiber}, for the free fiber regions can be estimated by the following relationship (22).

$$E_{fiber} = 1 - \exp\left[-\frac{4\,\bar{\rho}\,\eta L}{\pi d_f\,\rho_f}\right] = 1 - \exp\left[-\frac{4\,\beta\eta L}{\pi d_f}\right] \qquad (2\text{-}13)$$

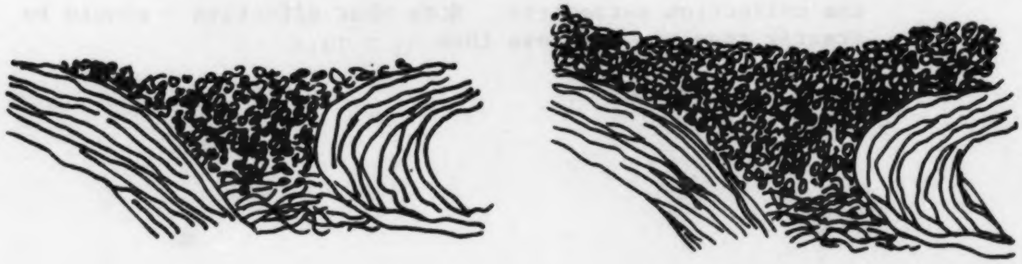
when the porosity or void fraction is 0.90 for the fibrous region. The terms $\bar{\rho}$ and ρ_f refer to bulk and discrete fiber densities, respectively; L is the bed thickness, d_f the fiber diameter, and η the single particle-single fiber collection efficiency for the relevant particle size and particle capture mechanism(s). The ratio ρ/ρ_f, which is defined as filter bed solidity, is usually represented by the symbol β. Solidity is related to filter porosity by the expression, $\beta = 1-\varepsilon$.

Estimates of single fiber collection efficiencies for coal flyash collection by inertial (η_I) and interception (η_{DI}) mechanisms are shown in Table 1 for a fiber diameter, d_f, of 8.5 μm and an actual flow velocity of 3.85 m/min. The latter value depicts an average pore velocity encountered with typical woven glass fabrics having an overall fabric areal density of 340 g/m^3. Although both mechanisms show η_I and η_{DI} increasing as particle diameter increases, the resulting efficiency values are far below those necessary to provide high efficiency removal. However, introduction of the single fiber efficiency parameter into Equation (2-13) in conjunction with


YARN
YARN
BULKED FIBERS
DUST

UNUSED FABRIC

EARLY DUST BRIDGING OF FIBER SUBSTRATE



SUB SURFACE DUST CAKE DEVELOPMENT

SURFACE DUST CAKE DEVELOPMENT

Figure 3. Schematic, dust accumulation on woven glass fabrics.

TABLE 1. COLLECTION PARAMETERS AND INITIAL EFFICIENCY FOR WOVEN FABRIC FILTERS FOR FIBER PHASE COLLECTION[a]

d_p (μm)	η_I	η_{DI}	Fractional[b] efficiency
1	0.02	0.003	0.014
2	0.10	0.01	0.44
3	0.30	0.023	0.83
4	0.45	0.041	0.93
5	0.60	0.064	0.97
10	0.80	0.26	0.996

[a] Filtering temperature of 20°C.

[b] Conservative estimates based on η_I alone, the larger of the collection parameters. Note that effective η should be greater than η_I, but less than $\eta_I + \eta_{DI}$.

best estimates for the free fiber bulk density, $\bar{\rho}$, and depth of fiber, L, prevailing in the pores of common woven glass fabrics lead to the overall fractional efficiency values shown in Column 4, Table 1 (48). One can infer that for the fabric of interest, inertial impaction is the controlling capture mechanism at the start of the fiber filtration phase. Additionally, respirable particles (<2 - 5 μm) are removed at very low efficiencies by the clean (unblocked) fibers, whereas larger particles (4 to 5 μm) are collected at 95 percent efficiency. Capture of the larger particles permits the bridging process to continue until a solid, unbroken dust cake is formed.

2.3.2.2 Final Cake Filtration Phase--

As more dust is captured by the fibers, the approaching gas stream encounters a mix of fibers surrounded by chain-like particle agglomerates that form a progressively better collection system as most dust accumulates. This process is represented schematically in Figure 3 that shows various stages of particle capture from the initial particle collection in the free fiber region to the ultimate formation of a superficial dust layer (31). When the proper fabrics are selected, the filter surface is relatively smooth, with only minimal indication of perforations or cracks. Once pore bridging has been accomplished, the dust collection properties of the filter are governed mainly by the dust layer. Theory indicates that the dust collection efficiency for a granular bed composed of uniformly sized particles may be expressed as follows (22):

$$E = 1 - \exp\left(\frac{-3\beta L\eta}{2d_c(1-\beta)}\right) \qquad (2\text{-}14)$$

where β is the ratio of the bulk density of the dust deposit, $\bar{\rho}$, to the density of the discrete or individual bed particle, ρ_p. The term $1 - \beta$, usually designated as ε, the bed porosity (or fraction void volume), ranges from 0.6 to <0.9 for many dust deposits. Dust layer thickness, L, granule diameter, d_c, and the single particle-single granule collection efficiency, η, are the remaining variables affecting particle capture.

Equation (2-14) can be derived from Equation (2-13) by adjusting for collector shape factor (sphere versus fiber) and by re-introducing the term $(1 - \beta)$ that was not included in Equation (2-13) because of small β values. Except for the hypothetical case where the particles to be removed come from a monodisperse (uniformly sized) population, practical application of Equation (2-14) requires integration over the range of particle sizes characterizing the approaching aerosol and the resultant dust deposit.

Before discussing theoretical collection efficiencies for the unperturbed dust layer, an illustration of the relative importance of the predominant capture processes associated with dust layer or "cake" filtration is given in Table 2 (48). Computations have been made for several particle diameters constituting a typical dust layer in which the estimated values for particle capture efficiency by diffusion, direct interception, and inertial impaction mechanisms are shown for two particle sizes in the gas stream undergoing filtration. It is again emphasized that these efficiency values reflect "single particle-single collector" behavior only. The overall removal for any size category, which depends upon the number of "collectors" dispersed in the

TABLE 2. ESTIMATED VALUES FOR DIFFUSION, INTERCEPTION, AND IMPACTION PARAMETERS FOR GRANULAR BED COLLECTION[a]

Collector diameter, d_c µm	Particle diameter					
	d_p = 0.25 µm			d_p = 1.0 µm		
	Diffusion η_D	Interception η_{DI}	Impaction η_I	Diffusion η_D	Interception η_{DI}	Impaction η_I
0.25	0.35	2.27	0.08	0.32	36.4	0.5
1.0	0.17	0.25	0.02	0.12	4.0	0.2
2.0	0.10	0.058	0.01	0.069	0.94	0.1
5.0	0.069	0.018	0.005	0.037	0.29	0.05
10.0	0.035	0.002	0.003	0.022	0.038	0.02

[a] Refer to Equations (1), (4), and (7).

filtration zone, must be computed using Equation (2-14). What is strikingly apparent, however, is that direct interception and diffusion are the controlling mechanisms for capture of the submicrometer particles.

Use of the interception parameter alone to estimate the overall glass fabric performance for varying thicknesses of fly ash deposits, Table 3, shows that collection efficiencies for 0.25 m particles rapidly approach 100 percent and that 1.0 m particles do not penetrate at all (48). Again, it is emphasized that the behavior of a uniform, unbroken, and unperforated dust layer is being described. Furthermore, no allowance is made for a very low level but distinct seepage of agglomerated particles through the underlying fabric structure that can contribute to small but detectable concentrations ~0.5 mg/m^3 (0.22 grains/1,000 ft^3) in the case of woven glass and down to 0.005 mg/m^3 (0.0022 grains/1,000 ft^3) as measured for sateen weave cotton (48).

Additionally, if a poor fabric selection is made, e.g., too open a fabric weave with a sparse, free fiber cover, the potential exists for the formation of pinhole leaks such as shown in Figure 4. When the tendril-like growth of agglomerate chains fails to interlock and bridge the space between adjacent fibers within a few minutes, the increasingly greater gas velocities through the leak region can prevent further particle accumulation. Hence, a characteristic pinhole develops as shown in Figure 4 (31,43,48). In the extreme case, a situation might evolve where a pinhole cross section representing about 5 percent of the filter face area actually accommodates 99 percent or more of the approaching gas stream. Because only the large (15 to 20 μm) particles fail to penetrate the pinholes, collection efficiency in the above example would be less than 1 to 2 percent (42).

Fortunately, a good fabric collector will seldom possess more than 200 pinholes (roughly 100 μm diameter) per square meter of filtration surface (less than 2 x 10^{-2} percent of the total fabric area). Once pore bridging has been accomplished, the dust collection properties of the filter are governed mainly by the dust layer.

Because real filters contain "less than perfect" regions where temporarily or permanently unblocked pores or cracks allow certain fractions of the inlet aerosol to penetrate the filter with negligible separation of >15 to 20 μm particles, the upstream and downstream particle size distributions are often almost identical. The above phenomenon, which is associated mainly with woven glass fabrics, is readily explained by the fact that 95 to >99 percent of the effluent dust comes from the air that has passed through the pinhole leak regions (31,47,49). In the case of highly efficient fabrics such as sateen weave cotton, the entering particle size distribution may be appreciably larger than that for the dust penetrating the filter (31,42).

2.4 GAS PROPERTIES (1-3, 24-26)

In preceding discussions of basic particle capture mechanisms, certain physical and kinetic properties of the gas stream (gas temperature, gas viscosity, and velocity) appear as major variables in several particle collection relationships. Moisture content and condensable materials, through

TABLE 3. ESTIMATED OVERALL WEIGHT COLLECTION EFFICIENCIES AS A FUNCTION OF CAKE THICKNESS AND INLET PARTICLE SIZE FOR COAL FLY ASH, MMD = 6.4 um, $\sigma g = 2.3$

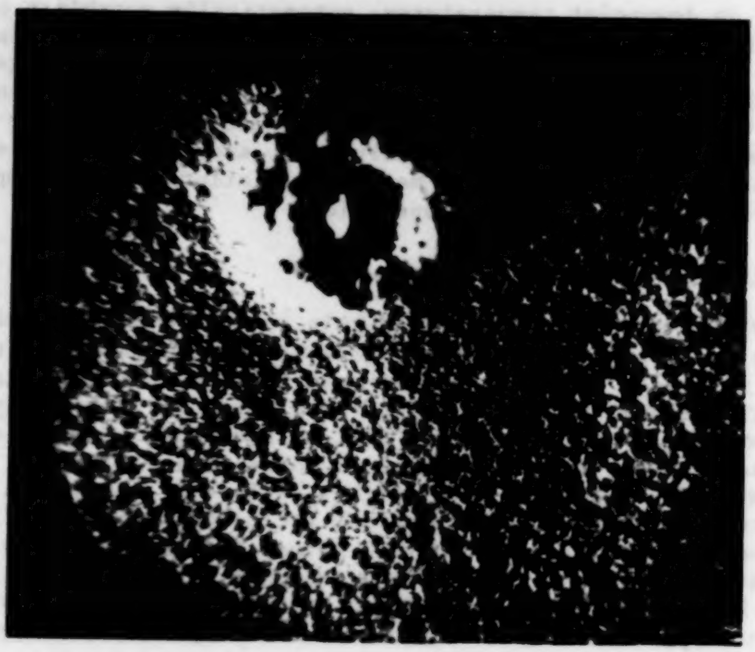
Cake[a] thickness μm	Areal density g/m^2	Estimated[b] filtering time min	Estimated percent efficiency Particle diameter, μm 0.25	 1.0
10	10	0.82	97.8	100.00[d]
20	20	1.64	99.95	100.00[d]
30	30	2.46	99.9999	100.00[d]
100	100	8.20	100.00[c]	100.00[d]

[a] Based on an assumed porosity of 0.5 (bulk density of 1 g/cm^3).

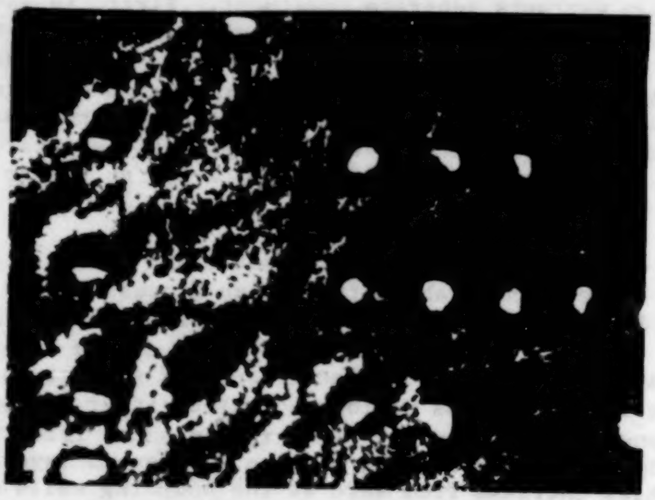
[b] Based on inlet concentration of 20 g/m^3 (8.7 grains/ft^3) velocity of 0.61 m/min (2 fpm).

[c] Actual estimate 99.00 followed by 16 "nines".

[d] Actual estimate 99.00 followed by 26 "nines".



(a). Pinhole leak, filtration surface, showing characteristic mound, substage lighting (20x magnification).



(b). Massive pinhole leakage with monofilament screen -- without loose fibergs.

Figure 4. Variations in pinhole leaks due to fiber presence and pore size.

their impacts on dew-point temperatures, automatically establish minimum operating filtration temperatures which, in turn, affect gas stream viscosity and velocity. Although the corrosive properties of the carrier gas stream may have no immediate effect on particle collection, the degradation of the fabric media will lead to irreparable damage within a matter of hours or days. Also the bag supporting members, baghouse structure, and gas handling equipment may eventually suffer damage leading to mechanical failure of key components necessary for proper filter system operation.

2.4.1 Temperature (49-57)

Gas stream temperature plays a key role in the design, operation, and performance of a fabric filter system. First, it determines the type of construction materials and fabrics that must be used. Second, its proper regulation will prevent the condensation problems cited previously. Third, gas temperature may play an important part in the control of gas stream reactions essential for removal of gaseous contaminants. Fourth, baghouse temperature will determine the total filter surface or cloth area requirement when the filtration velocity (or air/cloth ratio) has been specified. Fifth, gas stream temperature will also control volume flow requirements of the system exhaust fans due to its effect on gas density. Additionally, gas density also has a direct impact on fiber boundary layer thickness, which in turn, influences particle capture by direct interception, (see Equation (2-1).

2.4.2 Viscosity

2.4.2.1 Effect on Particle Collection (22,51,53,54)--

Although gas stream viscosity is temperature dependent, its independent role in filtration warrants separate treatment. First, in any particle collection process, the effect on increased gas viscosity is to retard particle motion across the gas streamlines or through a stagnant gas film (boundary layer). Thus, capture by inertial impaction effects is reduced as indicated by Equation (2-4). On the other hand, the random Brownian motion induced by molecular bombardment overrides the particle retardation by opposing forces, see Equations (2-4) through (2-8), such that collection by diffusional processes is enhanced.

2.4.2.2 Effect on Pressure Loss Through Dust Laden Fabrics (22,44,58,59)--

During all conventional fabric filtration processes, gas flow through the fabric and dust layer falls within the laminar or streamline range. Basically, this type of flow may be considered as a pure translational motion regardless of path when there is no interchange of gas between the adjacent streamlines. Resistance to gas motion generated either by constraining ductwork or by some obstacle in the gas stream results from the shearing action induced by velocity gradients between contiguous layers of the gas as the flow velocities increase from zero at the bounding walls or particle surfaces to their maximum levels at points most removed from constraining or contacting surfaces.

However, gas flow in the inlet and outlet ducts and also at most regions within the baghouse proper is usually in the turbulent range wherein a constant mixing or interchange of particles take place from one duct region to another. It was indicated previously that a fiber Reynold's number, Re_f, of 1.0 normally reflects laminar flow (see Equation 2). In most filtration applications, actual Re_f values range from 0.01 to 0.1. If one is concerned with the turbulence levels within a confined gas flow such as a duct system, the Reynold's number is computed by the following relationship:

$$Re_d = \frac{D_d V \rho_g}{\mu} \tag{2-15}$$

The only difference between Equation (2-2) and Equation (2-15) is that the duct diameter, D_d, replaces the characteristic fiber diameter, D_f. The remaining terms V, μ_g, and μ remain as defined in Equation (2-2). However, the bounding Re_d value below which the duct flow is laminar is roughly 2,000. Turbulent flow commences at Re_d values of 5,000 and transitional flow occurs at intermediate levels between 2,000 and 5,000. It should be noted that under turbulent flow conditions, which apply to almost all pathways of a filter system (hoods, ducts, breechings/manifolds, and stacks), the pressure losses will vary as the square of the velocity. Conversely, pressure losses through the fabric and dust cake vary linearly with velocity, provided that the dust deposition rate remains unchanged.

2.4.3 Velocity Effects

2.4.3.1 Filtration Velocity--

In addition to velocity changes arising from variable gas temperatures at a constant mass flow, there will be some industrial processes or utility boiler operations where variable ventilation or gas volume requirements demand a change in system flow velocities. As indicated earlier, particle capture by inertial impaction would be enhanced by a velocity increase, see Equation (2-4), whereas diffusional collection would be reduced, see Equation (2-8). In many filter systems, deviations from the ideal (such as fabric defects that may foster pinhole formation) may negate the theoretical advantages of increased filtration velocities (31,42,48). Additionally, the inherent problem of gradual dust seepage is usually aggravated by higher velocities through the fabric (31,42,48).

2.4.3.2 Duct, Breeching, and Hopper Velocities--

The transport of particulate materials from their point of generation to the gas cleaning device requires sufficiently high velocities to prevent particle settlement or diffusional losses to containment structure walls and floors. Underestimation of the transport or supporting velocities needed to prevent such losses in either horizontal or vertical ducts may lead to serious plugging problems (1,3,6).

A second result of sedimentation losses, including those that normally occur in the dust hopper per se as the gas stream cross section enlarges and/or changes direction, is to reduce both the concentration and the size properties of the solids actually reaching the fabric surfaces compared to those measured at some upstream sampling location (31,47,48). If the parameters determined at the upstream site are used for design purposes, it is possible that measured fabric pressure losses may be either higher or lower than predicted values. The explanation for the pressure loss uncertainties is based upon the unique permeability properties of a dust layer that depend, not only on the areal density (g/m^2) of the dust deposit, but also upon the particle size distribution of the dust (1). A complete listing of these effects is provided in a later section discussing the development and application of the specific resistance coefficient, K_2, of a dust (see Basic Filtration Concepts - Woven Fabrics).

2.4.4 Moisture, Condensables, and Corrosive Components (1-8,61-63)

The presence of moisture and other condensable substances is of paramount importance in determining the temperature at which filtration must take place. Moisture condensation alone is sufficient to produce sticky dust deposits that contribute to high operating pressure losses and cleaning difficulties. Maintaining gas stream temperature well above dew point levels at all points within a filter system at all times (including start-up), with particular emphasis on bag, duct, and wall surfaces, is a prerequisite to eliminating condensation problems. Should the air or gas stream contain even trace quantities of chemically corrosive materials (H_2SO_4, HF, HCl, etc) that can attack and degrade baghouse structural components with particular emphasis on fabrics, special attention must be directed to selection of fabrics and construction materials. It is important that the operating temperature be based upon the dew point of the material condensing at the highest temperature when that substance in liquid or solid form can present a fabric plugging or corrosion problem.

The reaction of active chemical constituents of a gas stream (sulfur oxides in the case of flue gases) with mineral components naturally present or injected into the gas steam followed by subsequent collection upon a fabric, may actually broaden filter system capability when there is a need to capture both fly ash and sulfur oxides (64). Experimental pilot systems have indicated sufficiently high (70 to 90 percent) SO_x removal to justify development of field prototypes. Two major operating criteria must be observed with the above "dry-scrubbing" systems: a guaranteed above-dew point temperature at all times, and a fabric medium that will not be attacked by the absorbable or adsorbable gas.

2.5 PARTICLE PROPERTIES

In the preceding review of particle capture mechanisms, it has been emphasized that particle size properties play a major role in determining filter efficiency and, as will be discussed in later sections, equally important roles in determining filter pressure loss and cleaning requirements. Therefore, information on dust concentration (mass basis), particle size distribution, and particle density is absolutely essential to assess or predict filter behavior. The greater the amount and accuracy of data pertaining to particle shape and surface properties, electrification phenomena, and gas and vapor sorption, the greater the chance of a successful filtration process.

Prior to discussing particle properties, it is very important that two terms frequently used in the emissions control area be correctly defined. The term particulate is an adjective describing the state of dispersion of either solid or liquid material, usually as an assemblage of small, discrete, solid particles or liquid droplets. Hence, one should refer to particulate material, particulate emissions, or to particulate states, but not to "particulates" alone. The term aerosol, which is often incorrectly construed to be synonymous with the term "particle" as in "aerosol size", actually describes a suspension of particulate material in a gas just as the term hydrosol refers to a stable liquid dispersion of suspended solids.

2.5.1 Particle Mass Concentration

The magnitude of the inlet dust concentration will determine how frequently a filter must be cleaned for any constant gas flow system (1). In the unusual case where inlet concentrations are very low, <0.1 g/m^3 (0.05 grains/ft^3), it may be necessary to inject a precoating dust to accelerate the formation of a dust layer so that collection efficiency can be elevated to acceptable levels (45) and to prevent excessive penetration of fine dust into the fabric interstices.

Particle sampling methodology suitable for the determination of collector inlet concentrations is described in many publications (65-68). Insofar as mass measurements are concerned, procedures recommended by EPA, such as Methods 5 and 17, that are described in the Federal Register (69) are prerequisite for compliance testing as well as for forming a rational basis for acceptance or experimental testing. Major criteria to be satisfied by the particulate sampling method may be summed up as follows:

- Any extractive sampling must be performed isokinetically (1,22,68,70) so that the mass concentration and size properties of the particulate material in the extracted gas volume are representative of those in the parent gas stream.

- The quantity of collected dust must be determinable by gravimetric (or appropriate indirect) means at some prescribed accuracy level, e.g., within ±0.1mg in the case of Methods 5 and 17 (69).

- Sampling must represent true average conditions with respect to duct cross section while simultaneously taking into account any temporal changes in gas flow or particulate composition. The required number of sampling points and their precise locations, which vary from one plant to another in accordance with individual design conditions, are indicated in the Federal Register (69).

It should be noted that gravitational settlement or inertial separation may actually lead to lower inlet concentrations and somewhat smaller particle sizes at the filter face in contrast to those determined well upstream.

2.5.2 Particle Size Distribution

Particle size properties affect filter performance in several ways. First, particle collectability during the initial stages of filtration through a new or "just-cleaned" portion of a fabric is strongly size-dependent, with the smaller particles being the more difficult to capture (1-8). As dust accumulates, the size-dependency factor diminishes rapidly for all practical purposes (31,42). Second, the size and shape of the particles determine the structure of the overlying dust cake with respect to its porosity and the number and effective diameter of the parallel flow channels through which the gas must pass. As particle size diminishes, the dimensions of the flow paths through the cake also decrease such that classical aerodynamics dictates an increased resistance to gas flow. Hence, a fine dust is invariably more difficult to filter than a coarse one. Third, the fabric cleanability; i.e., the ease with which a dust deposit can be separated from a given fabric, usually diminishes with decreasing particle size unless electrical charge or agglomeration effects render the cake structure more porous.

The simplest explanation for the above behavior is that a fine dust contains more particles not only per unit volume of dust but also per unit cross section of dust cake surface such that the number of contacting points between the dusty layer and the adjacent fabric surface is significantly increased (48,49). Since the adhesive bonds between these particles and fibers oppose dust dislodgement, the finer dust will require a greater energy input to attain adequate cleaning. The fact that particle size plays a key role in filtration requires that the best possible estimates of size parameters be made prior to designing or diagnosing the performance of a filter system.

Although a broad spectrum of particle sizing techniques and instrumentation is discussed in the literature (71-74), the number of methods available for practical field application is quite limited if one adopts the same representativeness criteria stipulated for mass concentration methods.

2.5.2.1 Particle Sizing by Cascade Impactor--

Insofar as fabric filtration is concerned, an instrument referred to as a cascade impactor is well suited for determining the size properties of inlet and outlet particles (75-80). Because of its importance, key design and operator parameters for these and other sampling devise are discussed in Appendix 1 along with documenting references describing calibrating procedures and comparative performance for various impactor designs.

Cascade impactors permit the fractionation of inlet dust samples on the basis of the mass (weight) fraction collected in each of several size ranges represented by successive impactor stages. Frequently, the characteristic size for particles captured by each stage is expressed as an aerodynamic diameter; i.e., the equivalent size of the collected particle if its mass were transformed to that for a unit density sphere. When the impactor measurements are grouped and plotted as a cumulative mass distribution on logarithmic probability paper, one can ascertain at a glance the size properties of a dust. Figure 5, which shows a typical mass distribution for a coal fly ash as determined by cascade impactor, indicates that 50 percent of the fly ash mass

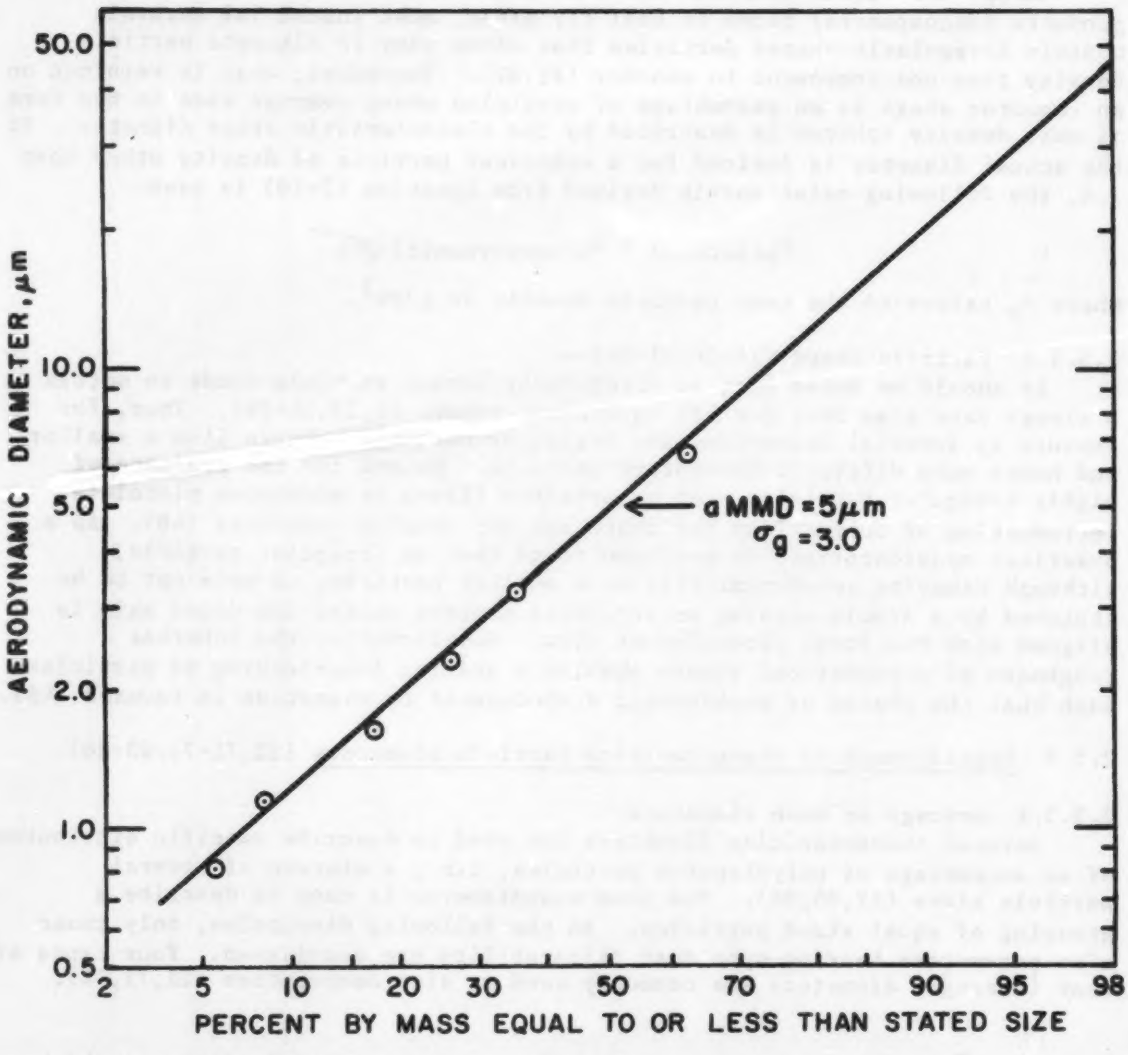


Figure 5. Mass distribution for typical coal fly ash, based on cascade impactor sampling (see Table 4).

is represented by particles less than 5 μm aerodynamic diameter and that 90 percent (5 to 95 percent) of the mass falls within the size range 0.8 to 30 μm diameter. As discussed in Section 2.5.3.2, the 50 percent size deduced from Figure 5 is the aerodynamic mass median diameter, aMMD.

2.5.2.2 Particle Density (1,22,24-26,71-74)--

Except for liquid droplets and the unique spherical mineral fusion products (cenospheres) found in coal fly ashes, most industrial aerosols contain irregularly-shaped particles that often vary in discrete particle density from one component to another (81,82). Therefore, what is retained on an impactor stage is an assemblage of particles whose average size in the form of unit density spheres is described by the characteristic stage diameter. If the actual diameter is desired for a spherical particle of density other than 1.0, the following relationship derived from Equation (2-10) is used:

$$D_{p(\text{actual})} = D_{p(\text{aerodynamic})}/\sqrt{\rho_p}$$

where ρ_p refers to the true particle density in g/cm^3.

2.5.2.3 Particle Shape (24-26,71-74)--

It should be noted that an irregularly formed particle tends to settle at a slower rate than that for its equivalent sphere (1,22,24-26). Thus, for capture by inertial impaction, the irregular particle behaves like a smaller, and hence more difficult-to-capture particle. Except for the presence of highly irregular particles such as asbestos fibers or micaceous platelets, introduction of corrections for shape are not usually justified (48). As a practical consideration, it has been found that an irregular particle, although behaving aerodynamically as a smaller particle, is more apt to be captured by a simple sieving or straining process unless its major axis is aligned with the local direction of flow. Additionally, the inherent roughness of nonspherical shapes enables a stabler interlocking of particles such that the chance of aerodynamic dislodgement or migration is reduced (48).

2.5.3 Significance of Characterizing Particle Diameters (22,71-74,83-86)

2.5.3.1 Average or Mean Diameters--

Several characterizing diameters are used to describe specific attributes of an assemblage of polydisperse particles, i.e., a mixture of several particle sizes (22,85,86). The term monodisperse is used to describe a grouping of equal sized particles. In the following discussion, only those size parameters bearing upon dust filterability are considered. Four types of mean (average) diameters are commonly used as size descriptors (22,71,74).

1. $\overline{D}$ = number average particle diameter, the particle diameter which multiplied by the total number of particles present will give the sum of all the particle diameters in the sample.

2. D_s = surface area average particle diameter, the diameter of the particle whose surface area multiplied by the total number of particles present will give the total surface area of all the particles in the sample.

3. D_v = volume average particle diameter, the diameter of the particle whose volume multiplied by the total number of particles present will give the total volume of all the particles in the sample.

4. $D_{vs} = D_v^3/D_s^2$ = diameter of the particle with the same ratio of volume to surface as that exhibited by all particles present in the sample.

The $\overline{D}$ value is of interest when particle capture is by sieving or direct interception, or when estimates of the pore dimensions within a dust layer or the probable length of an agglomerate chain are the principal concerns. The surface area average diameter, D_s, is more often associated with the surface-related measurement of light scatter for sizing purposes, although it is also important in the in situ absorption of SO_x (or other gases) prior to capture of their solid reaction products on a fabric. The volume diameter, D_v, which is directly proportional to the mass diameter for any constant density substance, relates mainly to collection processes where particle inertia plays a major role. For example, particle capture during the early stages of filtration and dust collection by cascade impaction are governed by the volume or mass diameter.

2.5.3.2 Median Diameters--

There are certain applications where the median or "middle-most" values for certain size parameters are very useful tools. Three such diameters are commonly encountered:

1. D_{nmd} or CMD = number or count median diameter, that particle size above which and below which there are an equal number of particles.

2. D_{smd} or SMD = surface area median diameter, that particle size above which and below which half the total surface area or total projected area of the distribution of particles is found.

3. D_{mmd} or MMD = mass median diameter, that particle size above which and below which half the total mass of the distribution of particles is found.

2.5.4 Characterizing a Distribution of Particle Sizes (1,2,8,22,24-26,71-74, 83,84)

2.5.4.1 Graphical Representation--

The particulate content of most aerosol systems is rarely distributed in accordance with a "normal" Gaussian distribution where all deviations from the central tendency can be described by the classical symmetrical "bell" curve. Except for highly truncated distributions, such as the limited range of particle sizes falling between two classifying screens or two cascade impactor stages, most particle size distribution curves are skewed such that the number of particles per equal size increment, increase geometrically as the size diminishes (see Figure 6,A).

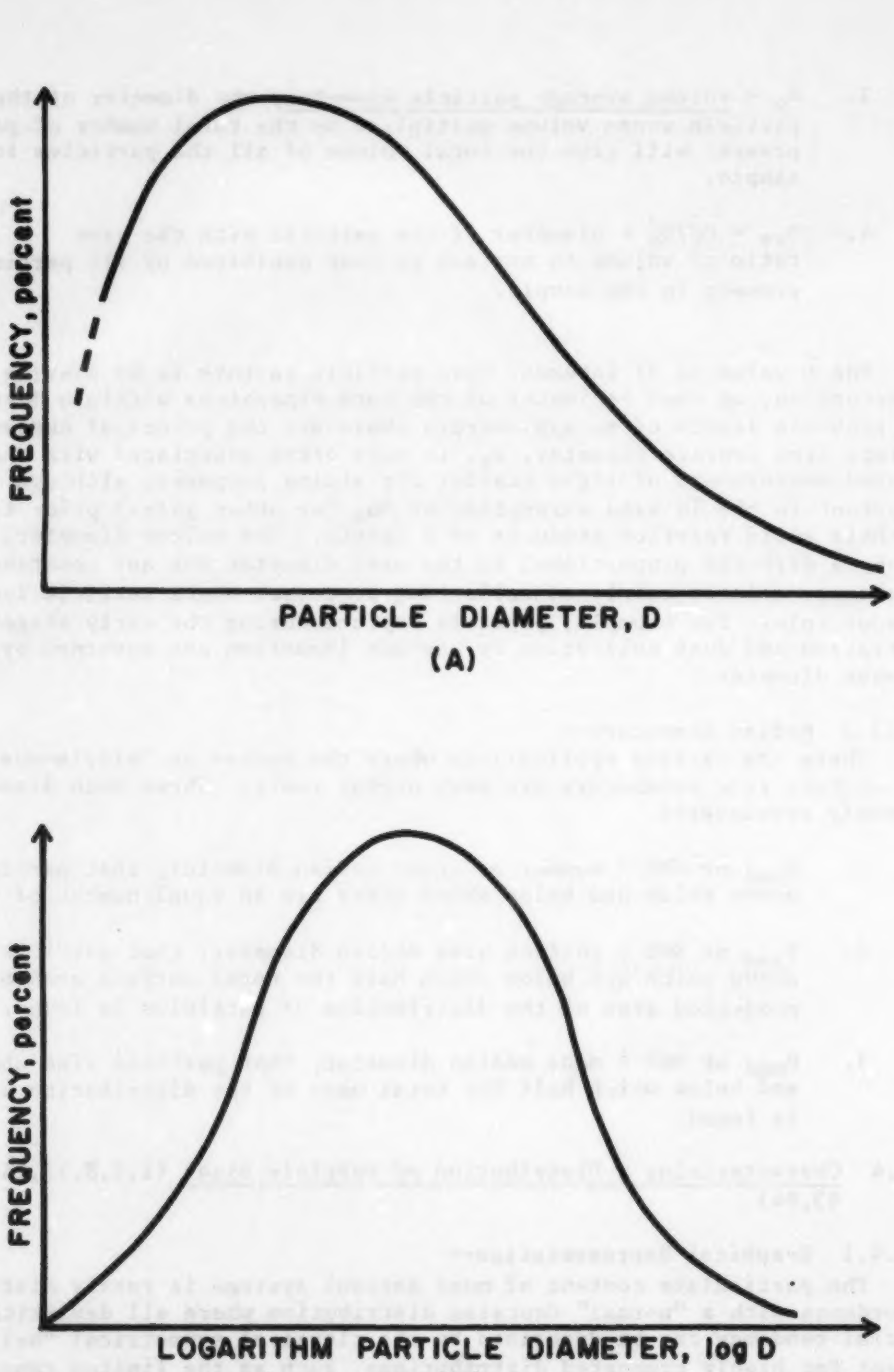


Figure 6. **Particulate material graphed as normal and logarithmic normal distributions.**

The mechanical processes of crushing and grinding to produce a finer product or the formation of a fume through condensation and/or agglomeration typify processes expected to produce asymmetrical distributions.

In many cases, a simple change of variable technique, namely that of substituting the logarithm of the particle size for the actual size, converts the skewed distribution to a symmetrical Gaussian form (see Figure 6,B). Special logarithmic probability graph papers are available that simplify the plotting of linear parameters as shown in Figure 5. The above approach is very useful because it applies equally well regardless of what size parameter is being investigated. For example, the logarithmic-probability plots for the cumulative number, surface area, and mass (or volume) distributions for a dust having NMD and σ_g values of 0.5 μm and 2.5, respectively, appear as shown in Figure 7. It should be noted that the slopes of the surface area and mass distributions are the same as that for the number distribution since σ_g, the geometric standard deviation, remains constant, regardless of the characterizing median diameter.

The abscissa on Figure 7 indicates the percent of total mass that is equal to or less than the size indicated on the vertical logarithmic scale. The size corresponding to the 50th percentile is the characteristic median diameter for the distribution. An attractive feature of this plotting method is that by computing the ratio of the ~84 percent to the 50 percent size or the 50 percent to the ~16 percent size, the distribution parameter or geometric standard deviation, σ_g, is determined, i.e.,

$$\sigma_g = \frac{84\%\ \text{size}}{50\%\ \text{size}} = \frac{50\%\ \text{size}}{16\%\ \text{size}}$$

In contrast to the normal Gaussian distribution in which the standard deviation bears the same unit as the attribute being measured, the change of variable procedure, i.e., the substitution of the logarithm of size for the actual dimension, results in the geometric standard deviation appearing as a dimensionless ratio.

If any mean or median diameter and σ_g are known, any other characterizing diameter may be estimated by graphical means (74), Figure 8, or calculated by means of the Hatch-Choate equations (87) Table 4. Despite the versatility of the logarithmic-probability distribution, it must be remembered that it is only as good as the fit of the actual data to the straight line that should result if, in fact, the measured size characteristics were exactly described by the log-normal approach.

Should a very poor curve fit result, one has recourse to many alternative distribution functions that may provide much improved correlations (88-92). The criterion for selecting one relationship in preference to another should be the goodness of fit to experimental measurements. All techniques are the same in principle; that is, the size is usually defined by D (or some function of D) and one or two arbitrary constants that provide a measure of homogeneity (range of sizes).

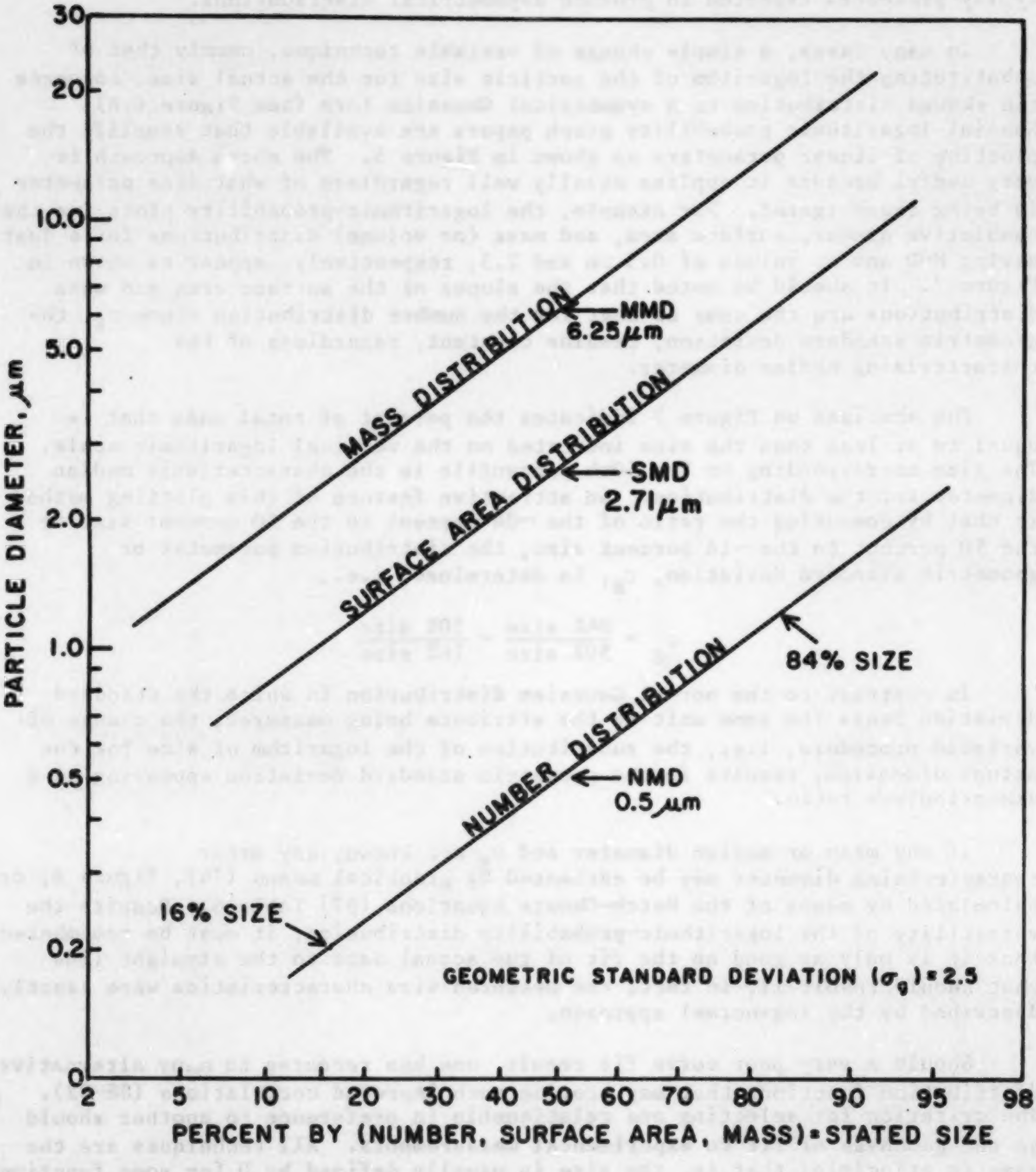


Figure 7. Particle size distributions based upon size, surface area, and mass (volume).

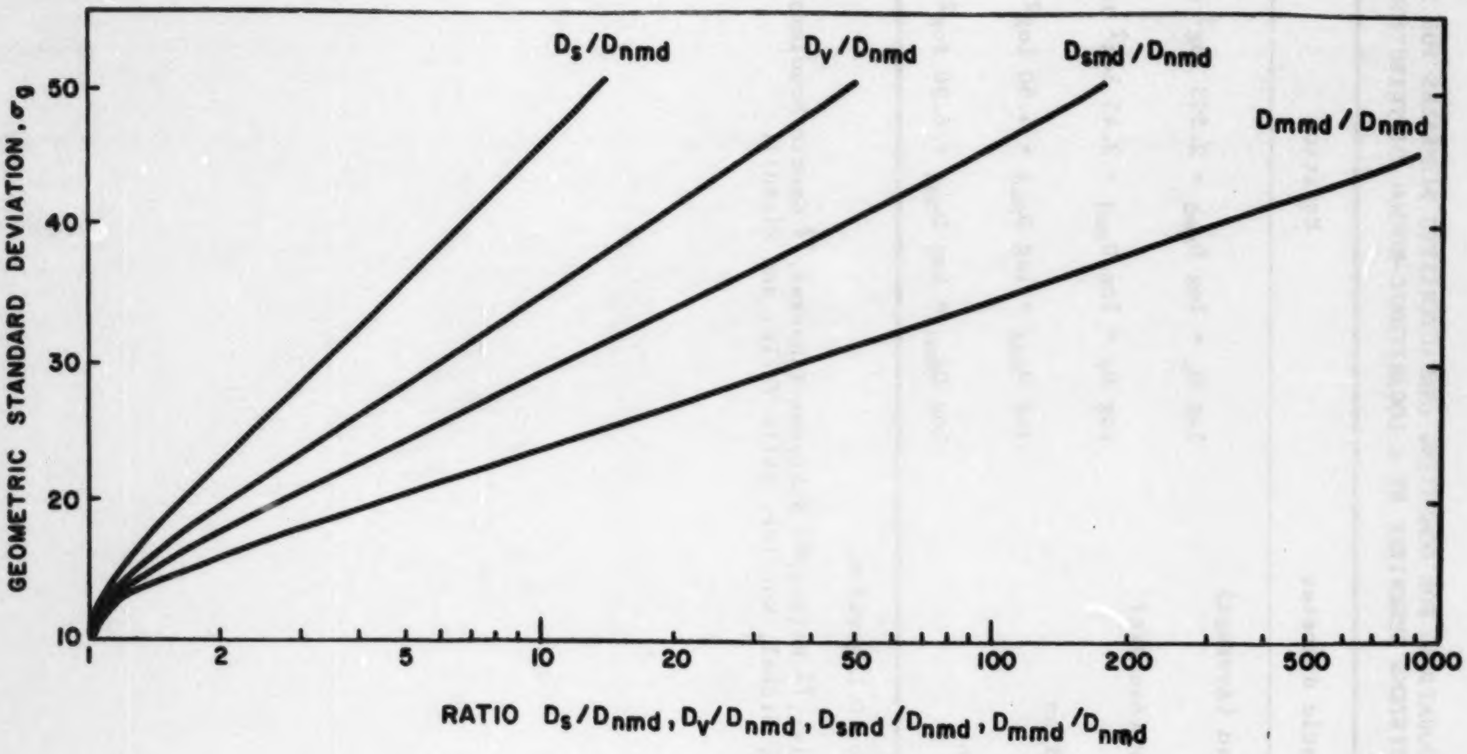


Figure 8. Graphical estimation of characteristic particle diameters (D_s, D_V, D_{smd}, and D_{nmd}) from count median diameter (D_{nmd}) and geometric standard deviation (σ_g).

TABLE 4. EQUATIONS FOR COMPUTING CHARACTERISTIC DIAMETERS FOR PARTICLE SYSTEMS DESCRIBED BY A LOGARITHMIC-NORMAL DISTRIBUTION

Characteristic diameter	Equation
Surface Mean (Average) D_s	$\log D_s = \log D_{nmd} + 2.303 \log^2 \sigma g$
Volume Mean (Average) D_v	$\log D_v = \log D_{nmd} + 3.45 \log^2 \sigma g$
Surface Median D_{smd}	$\log D_{smd} = \log D_{nmd} + 4.60 \log^2 \sigma g$
Mass Median D_{mmd}	$\log D_{mmd} = \log D_{nmd} + 6.90 \log^2 \sigma g$

NOTE: Base 10 Logarithm.

Rosin-Rammler,[72] Roller,[83] Nukiyama-Tanasawa,[72] Gaudin-Schulhmann,[84] Wynn-Dawes, Sichel, Kottler, Dalla Valle, and Wiebull.

2.6 FABRIC PROPERTIES AND FILTRATION CONCEPTS (1,93-106)

2.6.1 Fabric Selection Criteria

One of the most important components of a fabric filter system is the fabric. Although the dust retention characteristics of the fabric (which are usually defined in terms of fractional or percent dust penetration for the filter medium) are obviously important, the power requirements associated with operating pressure losses and fabric cleaning procedures and the capital and replacement costs for the fabric also play vital roles in fabric choice (1, 93-95). Additionally, the optimum fabric geometry for a given operation (tube, bag, or envelope), length-to-diameter ratios for bags or tubes, maximum possible length versus method of bag cleaning, and matching of fabric type and properties to the cleaning method and the working environment are also very important.

Krause (94) has designated the following fabric properties as essential to the proper function of any filter system, although not necessarily in the order delineated in Table 5.

2.6.2 Woven Fabrics (1,93-99)

2.6.2.1 Construction Features--

Woven fabrics are produced on a loom by the entwining of yarns in a variety of patterns in which the lengthwise yarns are referred to as warp yarns and the cross yarns are called fill, weft, or woof yarns. While there are a multiplicity of weaves, the most common types used for fabric filtration are the twill and sateen weaves. Simple "over-and-under" plain weaves are used occasionally.

The yarns, which constitute the fabric building blocks, are spun from staple (short) fiber lengths or continuous (synthetic) filaments that are twisted together to form threads. In practice, the final yarn or thread often consists of several plies (or smaller threads) that have been twisted together at varying twist levels. Staple yarns usually involve some 10 to 20 twists per inch whereas continuous, multifilament yarns such as those used in woven glass fabrics require fewer turns per inch to provide yarn strength and stability.

The warp yarns are always aligned with the bag axis (top to bottom) to provide maximum strength. In any combination of continuous multifilament and staple, bulked, or textured fill yarns, the much stronger multifilament yarns are always aligned from top to bottom. If both warp and fill yarns are woven from staple, the yarns with the higher thread count should be aligned with the bag axis.

Although the terms thread and yarn are synonymous, yarn usually refer to the composite threads making up the fabric, whereas the term thread often applies to the material used to stitch together various fabric shapes into the finished product. The yarns in many woven fabrics may be composed of hundreds of individual fibers twisted so tightly together that they are nearly impervious to gas flow. Therefore, unless the actual yarn dimensions are

TABLE 5. KEY FABRIC PROPERTIES

- **Solids retention - Weave characteristics must allow formation of a continuous surface dust layer, free of defects such as cracks or pinholes while minimizing internal plugging and blinding of pores.**
- **Clean fabric permeability - Airflow through the unused (clean) fabric must take place at minimal resistance as defined by Frazier permeability criteria (ASTM Standard D-737) while permitting a solid dust cake to form.**
- **Cleanability - Fabric surface texture must allow for sufficient dust release to allow for continuous filter system operation at acceptable pressure loss.**
- **Resistant to mechanical wear, high temperature, damage, and chemical attack.**

known, the weight of a fabric alone expressed in oz/yd^2 or g/m^2 may have little bearing on the pore area or free fiber content and hence its pressure loss or dust capture characteristics.

The explanation for the above statement is that pore diameter relates roughly to yarn diameter, whereas the state of dispersion of the fibers, i.e., twisted tightly into multifilament yarns or freely dispersed as with a napped surface, determines the dust capture and retention characteristics. Thread count alone affords but a rough index of fabric pressure loss; nominal thread (or yarn) diameter is again essential for any reliable estimates. Thread counts, usually written in the form 68 x 48 (27 x 19) refer to the number of warp and fill yarns per inch or centimeter of fabric width and length, respectively. Definition of terms commonly used to describe textile and filter fabric properties are given in Appendix C.

2.6.2.2 Fabric Performance versus Construction (1,96,97,99)--

It was pointed out previously that multifilament yarns spun from continuous filaments demonstrate poor dust capture properties unless the distance between the yarns is less than ten times the diameter of the particles to be collected. The above distance criterion depicts the approximate gap that can be bridged by a particle chain. Because pressure loss increases with yarn proximity, staple yarns or mixtures of multifilament yarns with staple, texturized, or bulked yarns are used to provide fiber obstacles within the pores (space between yarns). The same objective may be accomplished by the production of a surface nap which provides the highly effective free fiber cover characterizing napped, sateen weave cotton. The overall result is to enhance the bridging capability of the fabric while maintaining the fabric pressure loss per se at acceptable levels. Figure 9 shows typical warp (multifilament) yarns and fill (bulked) yarns used in twill weave woven glass fabrics (100).

If a fabric is woven as a plain weave from two yarn types, both sides of the fabric will present the same appearance. Furthermore, it makes no difference as to which direction the gas stream approaches the fabric. With twill weaves or other asymmetrical yarn patterns, however, one can expect differences in fabric performance depending upon which side is the filtering surface. For example, if the warp side is used with a 3/1 woven glass twill, 75 percent of the upstream surface will be made up of readily cleaned continuous multifilament yarns. Therefore, the surface dust layer will be dislodged more readily by any cleaning action which may afford a pressure loss advantage. On the other hand, the greater ease of cleaning from which one may infer a lower pressure loss can result in higher emissions because a larger fraction of more penetrable (cleaned) surface will be exposed when filtration is resumed (100). The same effect is observed if too severe a cleaning action is used.

2.6.2.3 Fabric Design Limitations (93,94,96,99)--

Although it might appear advantageous to design a fabric with a reduced thread count and a high free fiber content to provide both low fabric pressure loss and high particle collection, the actual application of such media could present some problems. First, an increase in yarn separation distance increases the chance for slippage under stress conditions such that nonuniform

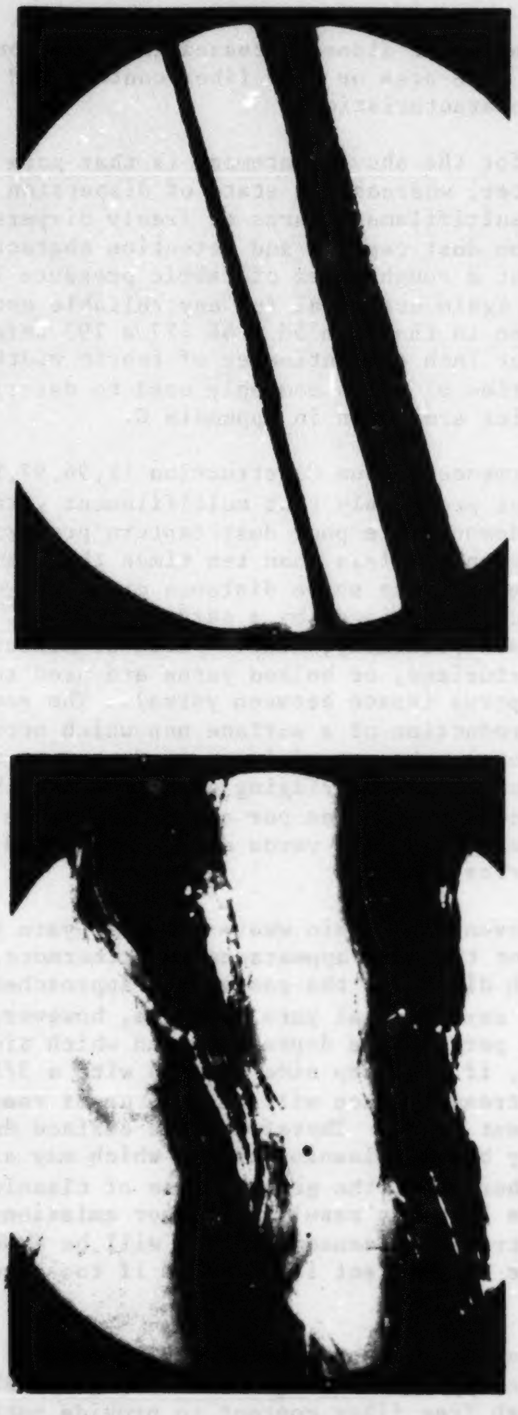


Figure 9. Continuous multifilament yarn (a) and bulked yarn (b), glass fabrics (100).

yarn spacing ensues. The resulting increased gas flow rate through these low resistance paths, whose free fiber support is weakened by the yarn separation, can lead to "blowout" or open pore formation followed by excessive particulate emissions (96,97,100). If special fiber coatings such as Teflon, silicone lubricants, or graphite are used to lubricate fibers to reduce abrading during tensile or lateral stressing, or to minimize chemical attack from corrosive aerosol components, the possibility of nonuniform yarn spacing is likely. This problem has been observed with common woven glass fabrics.

Yarn strength is essential to prevent excess fabric stretching and permanent deformation while filtering and especially during certain cleaning operations involving vigorous mechanical action. Otherwise, there is no advantage associated with the use of multifilament or tightly twisted staple yarns because far less free fiber collecting surface is available. One way to obtain more effective filtration is to use nonwoven media such as naturally felted or needle-punched felts to supply a maximum of collecting surface with a minimal fabric weight (1). The following discussion reviews the principal factors that must be considered for the successful application of felted fabrics.

2.6.3 Nonwoven Fabrics (93,98,101-104,106,107)

The advent of several synthetic fibers, many of which are highly resistant to damage by high temperatures and/or chemical corrosion, has been particularly advantageous in the development of felted media used in high capacity, pulse jet-cleaned collectors. Felted fabrics possess the marked advantage of providing a high, free fiber surface that permits clean, unused felt to function at relatively high efficiencies while still offering less resistance to air flow than most woven fabrics.

2.6.3.1 Construction Features - Felted Fabrics--

Natural wool felts prepared from animal fibers are inherently strong because of the scaly surface projections that assist the interlocking of the randomly dispersed fibers (1). In most filtration applications, felts are manufactured at areal densities ranging from 14 to 20 oz/yd^2, (475 to 675 g/m^2) roughly twice the weight of many woven fabrics. Because they are not composed of continuous yarns, they are more apt to deform when subjected to repeated rigorous stretching during cleaning by mechanical shaking (1,107). Additionally, the increased fabric weight also contributes to increased stiffness that will attenuate transmission of the shaking action over the full length of a bag. Therefore, effective utilization of felts has necessitated the development of different cleaning processes, reverse jet cleaning or pulse jet cleaning, to provide a continuous filtration capacity. Although both cleaning approaches allow for increased filtration velocities, pulse jet cleaning and its modifications are by far the most common methods for cleaning felted fabrics. In the case of pulse jet cleaning (107), the stiffness of the fabric does not inhibit effectiveness so long as bag lengths do not exceed 10 to 12 ft (3 to 3.7 m) and the volume of pulse jet air used is roughly scaled to the volume of the bag. Unfortunately, there are very definite upper temperature restrictions as well as corrosion factors associated with wool felts that usually restrict their use to near ambient temperatures, and always to the range below 65° to 95°C. Techniques used to clean filters and how they relate to fabric properties are discussed in detail in Section 3.

2.6.3.2 Advantages of Felted Media--

One advantage of felted media is that the increased porosity of the randomly dispersed fibers permits higher filtration velocities, nominally 6 to 10 ft/min (1.8 to 3 m/min) versus 2 to 3 ft/min (0.6 to 0.9 m/min) for most woven fabrics, while displaying minimal pressure loss increases for the fabric itself (1,93,95,98,107). This particular feature has led to the adoption of felted bags or tubes for use in pulse jet filter systems. The higher pressure loss that might be expected with increased filtration rate (and increased fabric loading) is avoided by more frequent and more intense cleaning plus the fact that the high (400 to 1000 g/m^2) residual dust layers on felted fabrics are characteristically more porous than those deposited on woven fabrics (107).

2.6.3.3 Needled Felts (1,98,99,107)--

In order to take advantage of synthetic fiber capability to function in difficult environments, it is necessary to compensate for the characteristic weakness of the unbonded, felted staple fibers that results from the general smoothness (and often slipperiness) of many synthetic fibers. One popular technique is to first prepare a sandwich consisting of an open, plain weave fabric composed of multifilament yarns (referred to as a scrim) and covered on each side with a layer of loosely felted fiber. Then by means of a needle punching process whereby specially barbed needles cause the surface felt fibers to intermesh and interlock with the scrim, a simulated felt is produced whose superficial physical properties are very similar to those of natural felts. Despite the fact that this needling creates regions of fiber alignment normal to the fabric surface at the needle locations, comparative evaluations of pressure loss and dust penetration behavior for both natural and needle-punched felts have indicated similar performance (107). From a structural viewpoint, the needle-punched felt permits the effective utilization of reverse jet or pulse jet cleaning without the risk of mechanical damage to the fabric.

2.6.4 Fabric Selection - General Comments (1,94,99,107)

Aside from the fact that the method of cleaning and the choice of fabric are frequently interrelated, there are usually several options available to the filter user that will satisfy his specific gas cleaning requirements. The ultimate target, in addition to meeting emission regulations for specific effluents, is to achieve the necessary degree of cleaning by the least expensive means (93,95,108-112). This will involve not only capital cost considerations, space requirements, and ancillary equipment used for waste dust handling and disposal, but also routine operating costs associated with fabric and parts replacement, power costs related to gas handling and fabric cleaning procedures, and most importantly, the maintenance regimen required to provide maximum filter system availability at the proper control level. To assist the filter user and inspection personnel, a listing of several common fabrics and their performance levels and suitability in difficult working environments (high temperatures and/or corrosive gases) is shown in Table 6.

TABLE 6. PHYSICAL AND CHEMICAL PROPERTIES OF FIBERS USED IN FILTER FABRICS

Fabric	S.G.[a]	Temp. limitations	Thermal properties	Chemical resistance	Other properties	Cost factor (Glass = 1.0)
Polypropylene	0.92	180°F	Similar to other polyesters. Heat degradation characteristics are essentially the same under dry and moist conditions.	Excellent resistance to most acids and alkalies. Will deteriorate in continued contact with concentrated nitric acid and certain oxidizing agents.	Virtually unaffected by aging. Excellent abrasion resistance. Sleekness of fibers provide good cake release.	
Cotton	1.50	180°F	Ignites readily. Burns steadily and is not self-extinguishing.	Disintegrated by hot or cold concentrated acids. Resistant to weak alkalies and organic solvents.	Virtually unaffected by aging. Moderately susceptible to the influence of microorganisms.	
Nomex	1.38	400°F	Does not support combustion. Decomposes at 700°F.	Very similar to nylon in chemical properties. Inferior to nylon in alkali atmospheres at elevated temperatures.	Like nylon, excellent resistance to abrasion, mildew, and aging.	2.78
Nylon	1.38	240°F	Moderatly difficult to ignite; self-extinguishing. Does not support spread of flame after removal of igniting source. Considered flameproof.	Hydrolyzed by concentrated acids. Loss of strength from hot weak acids. Virtually no effects from strong or weak alkalies. Unaffected by dry cleaning solvents; soluble in phenol and formic acid.	Virtually unaffected by aging. Resistant to the influence of microorganisms. Because of unusually high energy absorption, good in abrasion, flex life, impact loading, and dimensional stability.	
Orlon[a] (Acrylic)	1.18	275°F	Burns freely and rapidly. Fiber continues to burn after it is removed from flame. Fiber fuses and may shrink away from flame; forms dark irregularly shaped bead.	Stable in strong or weak acids. Attacked by strong alkalies. Attacked slightly by weak alkalies. Unaffected by common organic solvents.	Virtually unaffected by aging. Resistant to the influence of microorganisms.	1.0

(continued)

TABLE 6 (continued)

Fabric	S.G.[a]	Temp. limitations	Thermal properties	Chemical resistance	Other properties	Cost factor (Glass = 1.0)
Dacron[a] (Polyester)	1.38	275°F	Burns slowly when ignited; usually self-extinguishing when removed from igniting flame. Similar to nylon; fuses and shrinks away from the flame; forms round bead after cooling; hard to crush between fingers. Smoke dark and contains soot.	Dissolves with partial decomposition in concentrated sulfuric acid. Resistant to most mineral acids. Moderate resistance to strong alkalies at room temperature. Disintegrates in strong alkalies at boiling temperature. Good resistance to weak alkalies. Generally insoluble in organic solvents; soluble in some phenolic compounds.	Virtually unaffected by aging. Resistant to the influence of microorganisms. Physiologically inert; no poisonous or other harmful effects when used internally or applied externally.	
Teflon[a]	2.10	500°F	Excellent resistance to dry and moist heat.	Excellent resistance to mineral and organic acids, alkalies, oxidizing agents, and solvents.	Fair abrasion resistance.	3.8 (woven) 12.9 (felted)
Glass (uncoated)	2.54	550°F	Excellent resistance to dry and moist heat.	Excellent resistance to mineral and organic acids, oxidizing agents, and solvents. Poor resistance to alkalies.	Poor abrasion resistance.	1.0
Glass (coated) Teflon	2.40	~500°F	Excellent resistance to dry and moist heat.	Excellent resistance to mineral and organic acids, oxidizing agents, and solvents. Moderate resistance to alkalies.	Poor abrasion resistance.	~1.0
Glass (coated) Silicone-Graphite	2.40	~500°F	Excellent resistance to dry and moist heat.	Excellent resistance to mineral and organic acids, oxidizing agents, and solvents. Moderate resistance to alkalies.	Poor abrasion resistance.	~1.0

[a] Specific Gravity.

2.6.5 Basic Filtration Concepts - Woven Fabrics (1-4,93,94,98,113-120)

2.6.5.1 Total Pressure Loss (113-120)--

The total pressure loss, P, across any woven fabric filter is the algebraic sum of the loss through the fabric itself, P_f, (the latter serving mainly as the support for the dusty layer) and the loss through the dust layer, P_d, that provides the high efficiency collection capability.

$$P = P_f + P_d \tag{2-16}$$

The fabrics are usually sewn in the form of bags or tubes although envelope shaped designs are used occasionally. In most instances, the direction of filtration is from the inside to the outside of the bag, although the direction can be reversed if wire cages are used to prevent bag collapse. Because the air flow through fabric filters is always in the stream-line (laminar) range, pressure loss increases may be expected to vary linearly with the filtration velocity, V, and the areal density of the surface dust layer, W, i.e., $P \propto VW$, provided that the filtration velocity and the inlet dust concentration, C_i, remain constant over the filtration interval, Δt.

However, each dust-fabric combination will exhibit its unique pressure loss characteristic depending upon the respective air permeability properties of (a) the unused or clean fabric, and (b) the superficial dust deposit (1,107). With respect to a clean (unused) fabric, the Frazier permeability (see permeability Appendix A) indicates its air handling capacity per unit area (ft^3/min per ft^2 of fabric) when the pressure loss through the fabric is 0.5 in. water (125 Pa). Numerically speaking, the Frazier permeability (which is defined in English units) is equivalent to the filtration velocity or the common descriptor, air-to-cloth ratio. Because of progressive dust accumulation within the fabric structure over its service life, the Frazier permeability has little value for estimating overall filter system pressure loss and, except for purposes of fabric identification, is often a poor predictor of fabric dust collector efficiency. In practice, when pressure loss properties are cited for a fabric, they usually refer to actual or effective values for used but cleaned fabrics. Therefore, the basic working equation for computing the total pressure loss, P, through a surface element of a dust-laden fabric where filtration velocity and inlet dust concentration do not vary over the filtering interval becomes

$$P = K_f V + K_2 VW \tag{2-17}$$

In Equation (2-17), K_f is a special resistance coefficient reflecting the pressure loss characteristics for the cleaned regions of the fabric (1) and K_2 (114-116,118-120) is the specific resistance coefficient for the surface dust layer. Frequently, Equation (2-17) is presented in an optional form in which system pressure loss is normalized with respect to velocity; i.e.,

$$S = P/V = S_f/V + K_2W = S_E + K_2W, \tag{2-18}$$

where S is called the total filter drag and S_E refers to the "effective residual drag" for the cleaned fabric surface (113). The fabric loading accumulated over the time interval, Δt, may be expressed as:

$$W = C_i V \Delta t \ (g/m^2) \qquad (2\text{-}19)$$

The symbols and the units (metric and English) customarily used with the variables identified in this section appear in Table 7.

2.6.5.2 Graphical Estimation of S_E and K_2--

Figure 10 shows a typical filter drag versus fabric loading (S-W) curve for a woven fabric when filtration has been performed on a "completely cleaned" surface (120). Completely cleaned means that the entire surface dust loading, $W - W_R$, has been removed from the section of fabric undergoing evaluation. The term W_R refers to the residual fabric loading, i.e., the dust that remains more or less permanently embedded within the loose fiber structure of a filter following any normal field cleaning operation. Were dust-free air to be passed through the filter at velocity, V, the actual measured residual fabric drag would appear as S_R. For many practical filter operations, however, computation processes are greatly simplified without introduction of serious error if one extrapolates the linear (right hand) portion of the drag curve to the fabric loading level corresponding to W_R. The intercept at this point becomes the effective residual drag, S_E, appearing in Equation (2-18). The fact that S_E usually exceeds S_R means that any errors made in pressure loss estimation will be on the safe (high) side. The specific resistance coefficient, K_2, for the dust-fabric combination of interest is the slope of the linear portion of the S-W curve.

Although several theoretical methods have been proposed for calculating K_2 and S_E, the direct measurement approach is the only safe estimating procedure (46,49,100,120). Unfortunately, one is almost always compelled to perform such K_2 tests as single bag or single panel laboratory measurements with the constraint that the bags or test panels be completely cleaned before evaluations. If the test aerosol is generated by some high energy dispersion technique, it is necessary to ascertain that the particle size properties of the test aerosol provide a fair simulation of field conditions. Probable ranges for K_2 and S_E for various dust-fabric combinations are given in Table 8.

2.6.5.3 Pressure Loss Characteristics and Filter Performance (120,121)--

Inspection of Figure 10 shows that a high value for K_2 also signals a potentially high filter pressure loss. Additionally, the filter drag S_E at the resumption of air flow is an indicator of the lowest possible pressure loss that can be expected with conventional cleaning techniques for a given dust-fabric combination and a specified filtration velocity. (100,107,121)

If the pressure loss increases rapidly due to a high K_2 value, more frequent cleaning will be needed to keep the total system pressure loss within the static pressure capabilities of the induced draft fan and the failure limits (collapse, or buckling) of the baghouse per se. Because the dust penetration properties for the filter system depend upon the thickness of the dust layer, frequent cleaning to reduce pressure loss can adversely affect its dust retention characteristics (1). Additionally, complete fabric cleaning;

TABLE 7. SPECIAL NOMENCLATURE, ENGLISH AND METRIC EQUIVALENCIES FOR KEY FILTRATION PARAMETERS

	Symbol	Units		Equivalency
		Metric	English	
Filter resistance	P	N/m^2	in. H_2O	249 N/m^2 = 1 in. water
Filter drag	S	N min/m^3	in. H_2O min/ft	817 N min/m^3 = 1 in. water min/ft
Velocity	V	m/min	ft/min	0.305 m/min = 1 ft/min
Volume flow	Q	m^3/min	ft^3/min	0.0283 m^3/min = 1 ft^3/min
Fabric area	A	m^2	ft^2	0.093 m^2 = 1 ft^2
Areal density	W	g/m^2	lb/ft^2	4,882 g/m^2 = 1 lb/ft^2
Specific resistance coefficient	K_2	N min/g-m	in. H_2O min ft/lb	0.167 min/g-m = 1 in. H_2O min ft/lb
Dust concentration	C	g/m^3	$grains/ft^3$	2.29 g/m^3 = 1 $grain/ft^3$

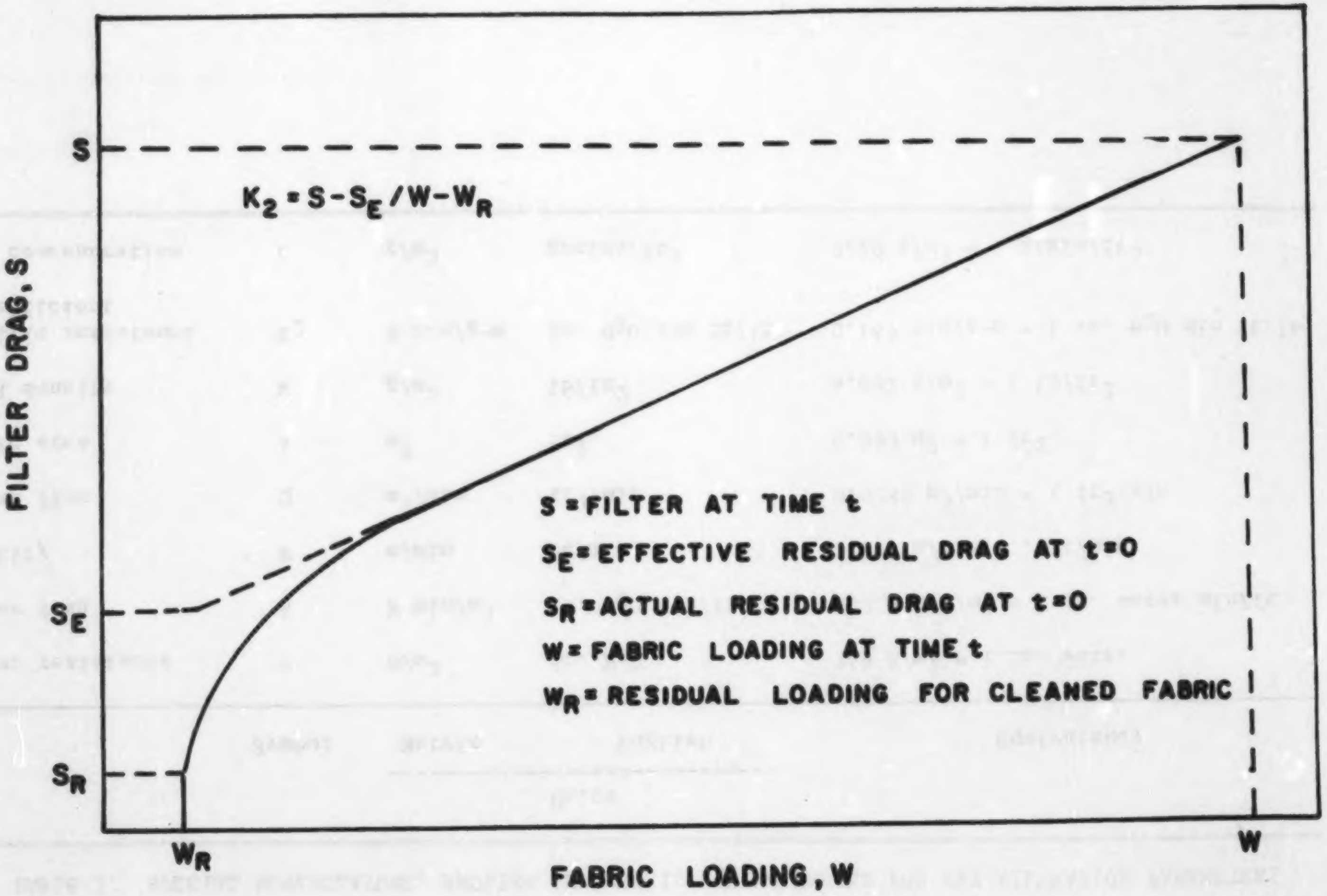


Figure 10. Typical filter drag versus fabric loading curve (100).

TABLE 8. PROBABLE RANGES FOR K_2 AND S_E, BASED ON LABORATORY TESTS (100)

Fabric	Dust	Size MMd (μm)	Size σg	Filtration velocity m/min	K_2^a N-min/g-m	S_E^a N-min/m^3
Woven Glass 3/1 Twill	Coal fly ash	4.2	2.4	0.92	1.85	115
Woven Glass 3/1 Twill	Coal fly ash	6.4	3.3	0.61	1.40	352
Woven Glass 3/1 Twill	Coal fly ash	11.3	3.6	0.85	0.75	150
Woven Glass 3/1 Twill	Lignite	8.8	2.5	0.61	1.34	270
Woven Glass 3/1 Twill	Granite (Rhyolite)	9.2	4.8	0.61	1.38	205
Woven Glass 3/1 Twill	Granite (Rhyolite)	1.2	2.4	0.61	12.3	--
Napped Sateen Weave Cotton	Fly ash	4.2	2.4	0.92	1.85	49
Napped Sateen Weave Cotton	Fly ash	2.4	1.77	0.92	1.77	--
Napped Sateen Weave Cotton	Talc	2.8	2.9	0.92	4.7	--

[a] Measured at 21°C, 760 mm Hg.

i.e., 100 percent dislodgement of the surface dust layer, is never realized with mechanical shaking or reverse flow cleaning systems. Therefore, when air flow resumes following cleaning, the low resistance "just cleaned" regions will display high transient velocities (up to 10 times the average value) (121). This phenomenon further aggravates the high emission problem caused by frequent cleaning and reduced dust layer thickness (areal density).

2.6.5.4 Effect of Partial Cleaning on Filter Drag-Fabric Loading Relationships (46,49,100)--

The primary reason for not being able to utilize most field data for K_2 estimates is that the fraction of filter surfaces completely cleaned normally ranges from roughly 5 to 50 percent for most commercial applications. The lower levels of cleaning, ~5 to 35 percent, apply to filter fabrics cleaned by bag collapse and reverse flow, whereas the 50 percent level is achievable with vigorous mechanical shaking (100,107). In either case, the bag compartment undergoing cleaning is isolated from the on-line compartments by appropriate dampers. In the case of relatively new bags or those that have not been affected by moisture condensation and/or chemical reaction, the dust usually separates at the dust/fabric interface where adhesive bonds are weakest (46). After cleaning, the fabric surface presents a patchy appearance in which the cleaned areas appear as the brightly illuminated regions in Figure 11 (46). Conversely, the black areas are regions of the fabric surface from which no dust has dislodged as a result of the cleaning action.

When filtration is resumed with a partially cleaned surface, (see Figure 12), gas velocity and dust deposition rates differ widely, with the greatest gas flow occurring through the "just cleaned" region. As filtration progresses, flow rates and dust distribution eventually approach the uniform level typified by a "completely" cleaned fabric. Until equilibration has again been achieved, however, the characteristic slopes of the curves for various levels of partial cleaning no longer permit a direct estimate of the true K_2 value for the dust. Thus, such curves should never be used to estimate K_2 for purposes of predicting filter performance (46,100,120).

During troubleshooting operating, it is important to note that most baghouse pressure loss indicators reflect the average pressure loss across several compartments operating in parallel. Hence, these data, just as those presented in Figure 12, cannot be used to estimate dust K_2 values. The reason again is that the dust loadings are not uniformly distributed from compartment to compartment nor across the surface of individual bags.

2.6.5.5 Nonlinearities in Drag-Fabric Loading Curves (120)--

Although the S-W curve shown in Figure 12 has been depicted as essentially linear over the upper ~75 percent of its range, the reader is cautioned that nonlinearities often occur with many dust-fabric combinations despite a uniformly distributed fabric dust loading. If the curvatures are minor, an eyeball or a least squares force fit to a straight line will entail little error. It is important, however, for purposes of interpretation, to recognize the reasons for nonlinearity. Figure 13 shows various S-W curve shapes encountered during field and laboratory studies. If the surface of a filter is nearly planar as it is for membrane filters used for particulate sampling or for special fabrics having a fluorocarbon or Teflon film laminated

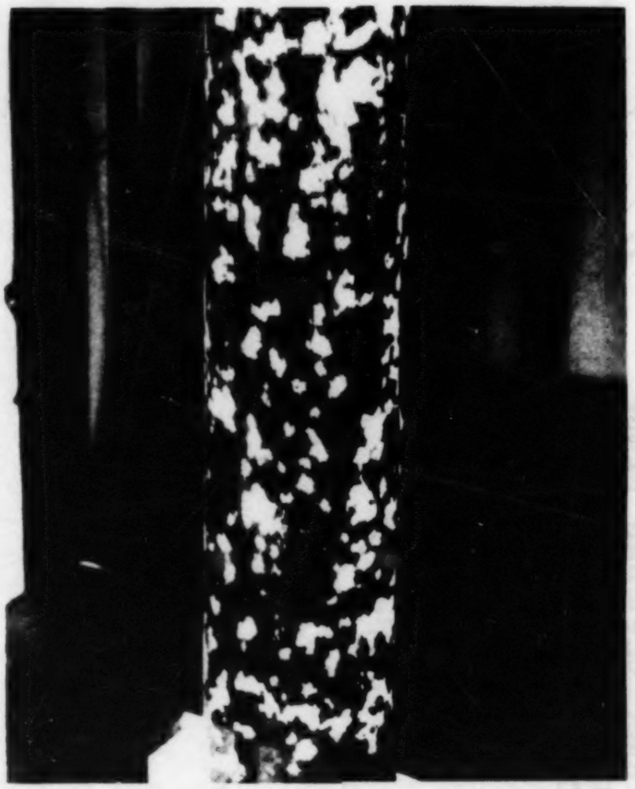


Figure 11. Cleaned bag with illumination from inside by fluorescent tube (46).

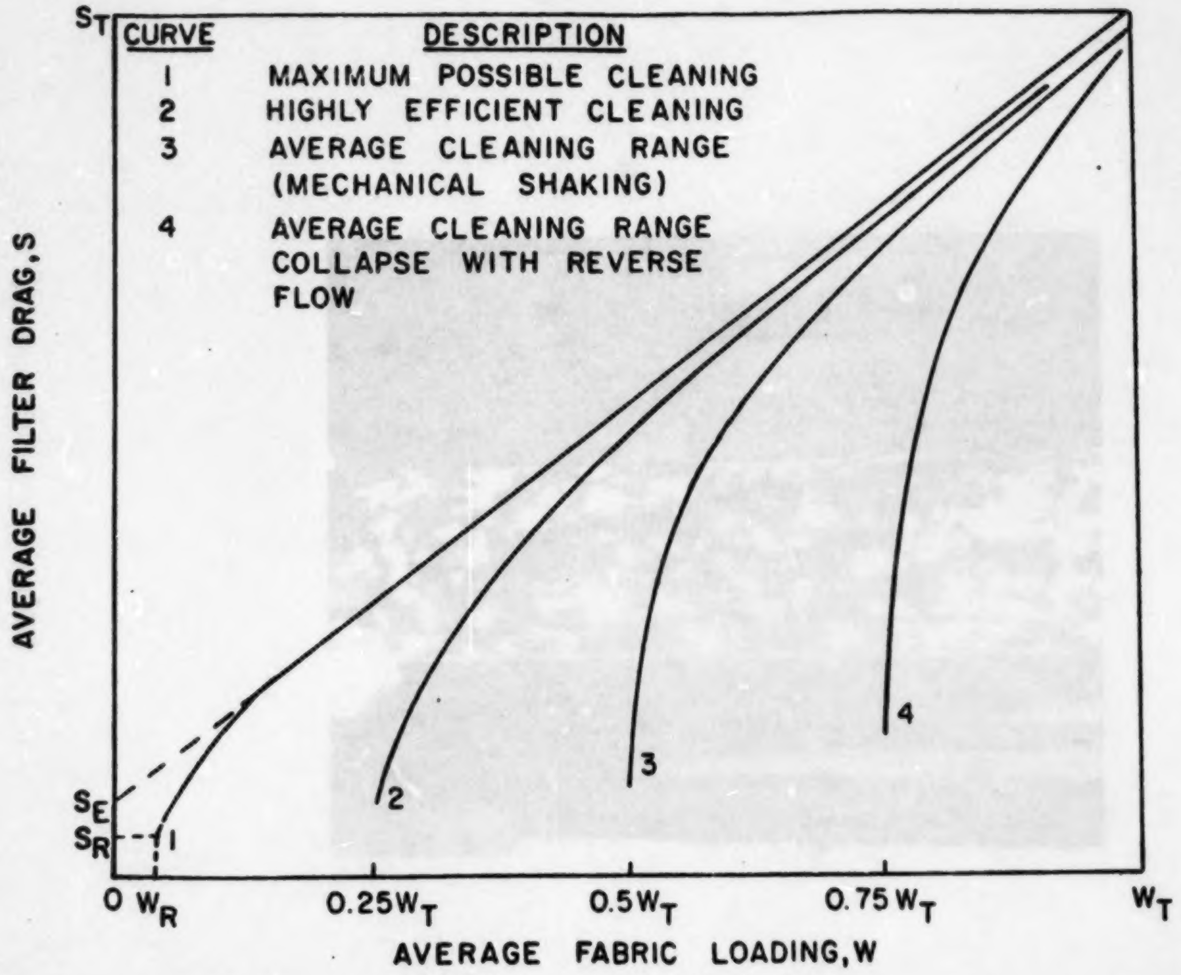


Figure 12. Typical drag versus loading curves for filters with different degrees of cleaning and a maximum allowable level for terminal drag, S_T, and terminal fabric loading, W_T (100).

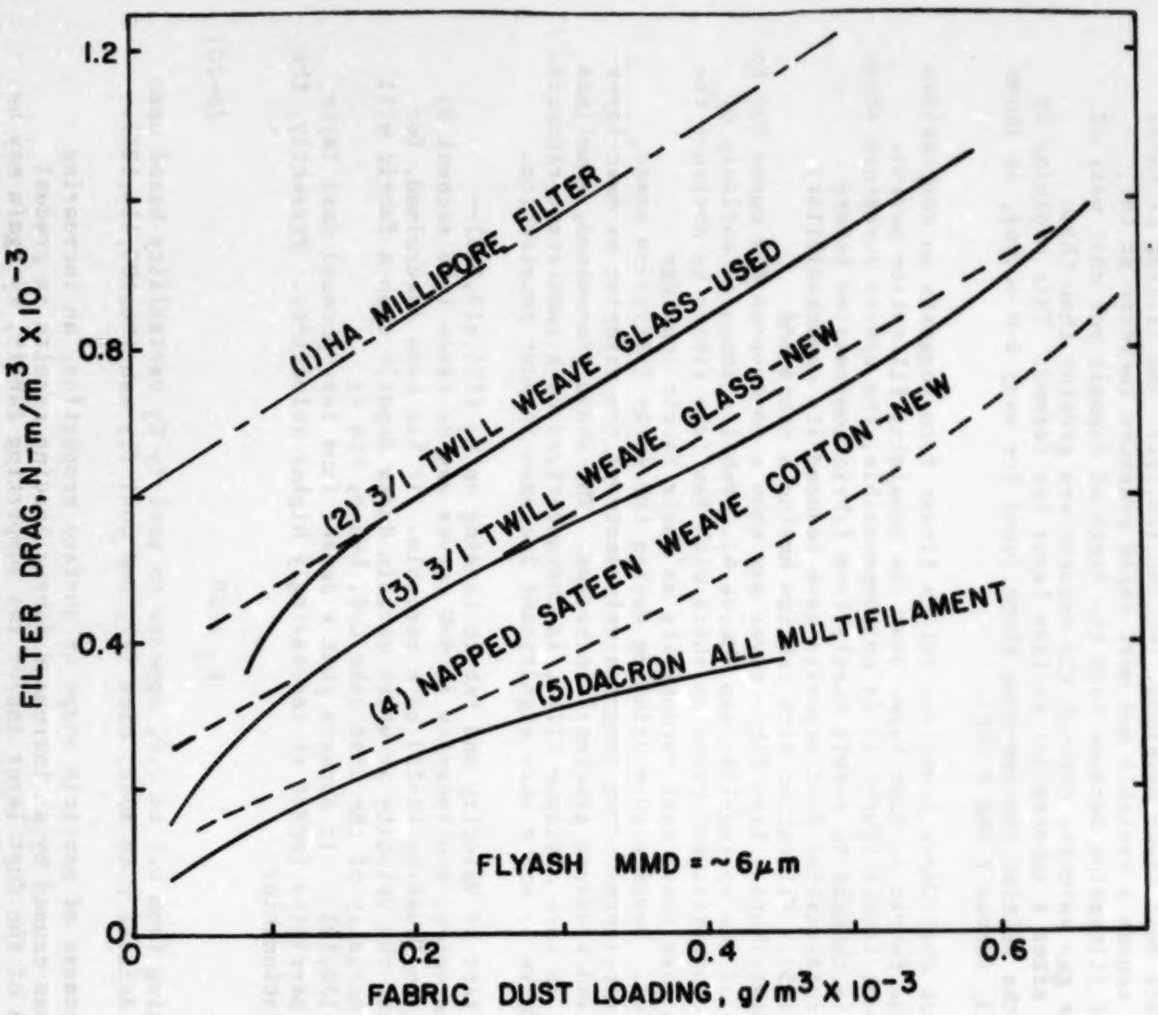


Figure 13. Approximate drag versus fabric loading, coal fly ash filtration at 0.61 m/min filtration velocity.

to a woven fabric, the individual pressure losses for the filter medium and the dust layer are completely independent. With the further constraint that the dust layer (or filter medium) undergo no compression as the dust loading accumulates, the S-W relationship, Curve 1, will be linear.

In the case of fabrics woven from a blend of continuous multifilament and bulked yarns, the depressions and gaps between the yarns must be filled before a true surface dust layer develops. (46,100,120,121) The filling of these depressions causes a variable and more rapid pressure increase at the inception of filtration because both the depth of deposit per unit mass of dust and the gas velocity through the deposit are greater than those encountered after a substantial surface layer has formed. This explains in large part the initial concave-down shape found for many S-W curves, as shown in Figure 13, Curves 2 and 3 (46).

The fact that Curve 2 evolves into a linear form suggests no compression of either the fabric or dust layer over the remaining filtration period. Since the dust itself (Curve 1) is noncompressible, the upward curvature shown in Curve 3 is thought to result partly from fabric compression before increasing interstitial dust deposits have reduced its compressibility (Curve 2) (115). Filtration with fabrics having a dense and uniformly-distributed, free fiber cover may show a concave-up S-W curve due to compression of the spring-like nap (Curve 4). Fabrics composed entirely of continuous, multifilament yarns or those with few free fibers to obstruct the pores often lose their dust retentivity as their fabric loadings increase (46). Despite pore bridging during the early filtration stage, increasing aerodynamic drag progressively destroys the bridging as dust layer thickness (and pressure gradient) increases. The above phenomenon, sometimes referred to as pore collapse (114), is characterized by a consistent reduction in slope (Curve 5) and a very significant increase in dust penetration.

2.6.5.6 Effect of Velocity and Fabric Loading on K_2 (115,117,119)--

In some cases, nonlinearity in S-W curves may be taken into account by treating K_2 in Equation (2-18) as a variable. It has been determined, for example, that the velocity at which certain dusts deposit upon a fabric will affect the porosity of the dust cake and, hence, its K_2 value (114,120,121). It appears that a denser (and less porous) dust layer results as particles impact at increasingly higher velocities. Presently, the general relationship:

$$K_2 \propto V^n \tag{2-20}$$

with n ranging from 0.2 to 1.0, appears to satisfy K_2 variability based upon tests with Arizona road dust, mica (2), and coal fly ash (46,100,114,121).

If, because of particle shape or surface properties, an increasing pressure loss caused by an increased fabric loading results in gradual compression of the dust layer and/or the supporting fabric, K_2 again may be treated as variable, with the general expression:

$$K_2 \propto W^n \tag{2-21}$$

serving to describe K_2 variability (49). Hence, K_2 as used in Equation (2-18) may be treated as a constant or expressed as some function of V and/or W as suggested by field or laboratory behavior. For example, when filtering coal fly ash, the equation:

$$K_2 = 1.8\ V^{0.5}\ (\text{N min/m}^3), \qquad (2\text{-}22)$$

where V is expressed in m/min, indicates K_2 variability with filtration velocity (122).

2.6.5.7 Theoretical Estimation of K_2--

Although the subject of calculating K_2 values has been treated extensively on the basis of fluid mechanics for both fibrous and granular beds, no complete theory has yet evolved. For estimating purposes, a relationship often referred to as the Kozeny-Carman Equation affords crude estimates of K_2 for granular beds (dust cakes) composed of near-spherical particles when particle shape, chemical species, and density are size-independent and interfering effects such as fluid boundary layer thickness, electrical charge, density, and gas adsorption sites may be ignored (1).

$$K_2 = k\mu\ \frac{36}{d_p^2}(1 - \varepsilon)/\rho_p\ \varepsilon^3 \qquad (2\text{-}23)$$

or

$$K_2 = k\ \mu\ S_o^2\ (1 - \varepsilon)/\rho_p\varepsilon^3 \qquad (2\text{-}24)$$

The terms appearing in Equations (2-23) and (2-24) are defined as follows:

k = Kozeny-Carman constant, usually stated to be 5.0. For estimating purposes, a value of 1.6 is more realistic for coal fly ash (46).

μ = gas viscosity, poise

d_p = particle diameter with a monodisperse system, cm

S_o = ratio of particle surface to particle volume, cm^{-2}

ε = dust cake porosity, dimensionless

ρ_p = particle density, g/cm^3

The porosity or fraction void volume, ε, within the dust cake is defined by term $1 - (\bar{\rho}/\rho_p)$ where $\bar{\rho}$ is the previously indicated bulk density and ρ_p is the discrete particle density. More sophisticated relationships have been proposed for those cases where the dust cake porosity exceeds 0.80. Regardless of which equations are used to compute K_2, however, the accuracy levels are too low to provide reliable data inputs for the solution of real filtration problems. On the other hand, the relationships indicated in Equations (2-23) and (2-24) do provide excellent qualitative guidelines for predicting K_2 variability.

Limited comparisons have indicated that a correction factor of roughly 1/3 should be introduced in both Equations (2-23) and (2-24) to account for the fact that the average calculated K_2 values are three times the actual measured values (46, 48). Thus, an effective value of 1.6 should be assigned to the Carman-Kozeny constant, k. This correction has been included in the computer program described in References 46, 48, 49 and 100 for the estimation of performance parameters for woven fabric filters.

Since real aerosols are polydisperse, i.e., they include a broad range of sizes, Equation (2-24) containing the specific surface parameter S_o is the better choice to calculate K_2. Use of the particle size parameters obtained from Andersen impactor measurements, MMD (actual value) and σ_g allows for ready estimation of S_o (46,48).

$$S_o = 6\,\frac{10^{1.151 \log^2 \sigma_g}}{\text{MMD}} \qquad (2\text{-}25)$$

2.7 FABRIC CLEANING - WOVEN AND NONWOVEN FABRICS (1,3,7,28,29,107,121-131)

Fabric filtration is effective only when the filter can be cleaned periodically and economically without impairing collection efficiency or disturbing the system gas flow. Highlights of recent studies on filter cleaning by (a) mechanical shaking, (b) reverse flow, (c) combinations of (a) and (b), and (d) pulse jet cleaning are described next. In the following discussions, fabric cleaning by various techniques is examined in terms of the physical process of dust removal, including the amount of energy required and the relationships among the degree of cleaning accomplished, energy inputs, and dust adhesion to the fabric.

2.7.1 Mechanical Shaking (1,107,122)

In a simple shaking system, the oscillation of the shaker arm alternately accelerates and decelerates the dust-laden bag surfaces. The resulting tensile and/or shearing forces exerted at the fabric-dust layer interface, if greater than local adhesive forces (1,46,48,132-135), will remove layers or flakes of dust from the fabric as shown in Figure 11 (121) that rapidly disintegrate to form a broad size spectrum of agglomerated and discrete particles (107,121). Although the shaking action is usually applied at the top of a bag, a bottom connection is sometimes seen in field installations (1). Typical mechanical linkages for bag shaking as well as bag configurations are shown in Figures 14 through 16. Further data on cleaning mechanisms for various baghouse designs are given in Appendix D while suppliers of fabrics and/or baghouses are listed in Appendix E.

The separating force, F_S (assuming that tensile and shear forces are roughly equivalent), can be estimated from the dust loading, W, and the average acceleration, $\bar{a}$, imparted to the dust-laden fabric (46,48).

$$F_S = W\,\bar{a} \qquad (2\text{-}26)$$

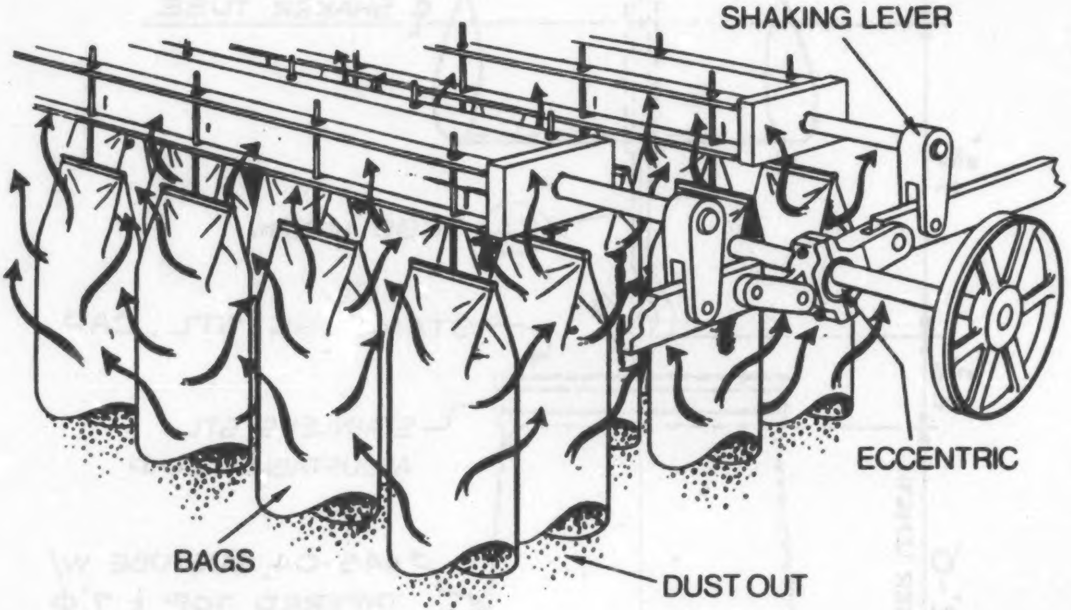

SHAKING LEVER
ECCENTRIC
BAGS
DUST OUT

Figure 14. Typical shaking mechanism (courtesy of the McIllvaine Co.).

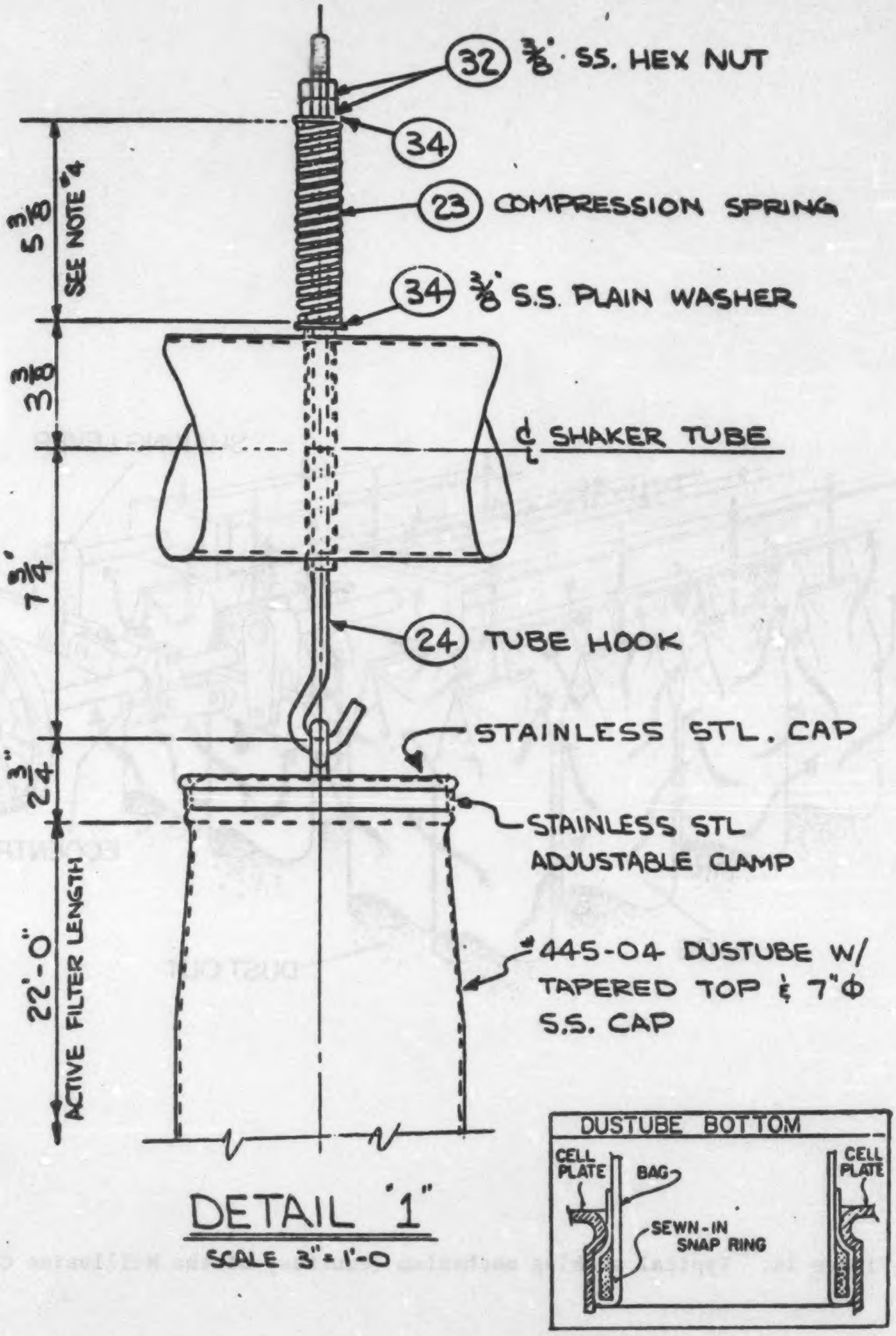

32
3/8" SS. HEX NUT
34
23
COMPRESSION SPRING
34
3/8" S.S. PLAIN WASHER
5 3/8
SEE NOTE #4
3 3/8
℄ SHAKER TUBE
7 3/4"
24
TUBE HOOK
STAINLESS STL. CAP
2 3/4"
STAINLESS STL
ADJUSTABLE CLAMP
22'-0"
ACTIVE FILTER LENGTH
#445-04 DUSTUBE W/
TAPERED TOP & 7"Φ
S.S. CAP
DETAIL "1"
SCALE 3" = 1'-0
DUSTUBE BOTTOM
CELL PLATE
BAG
SEWN-IN SNAP RING
CELL PLATE

Figure 15. Typical bag attachment system for a shaker baghouse (courtesy of Wheelabrator-Frye, Inc.--Drawing No. SD 1227-1).

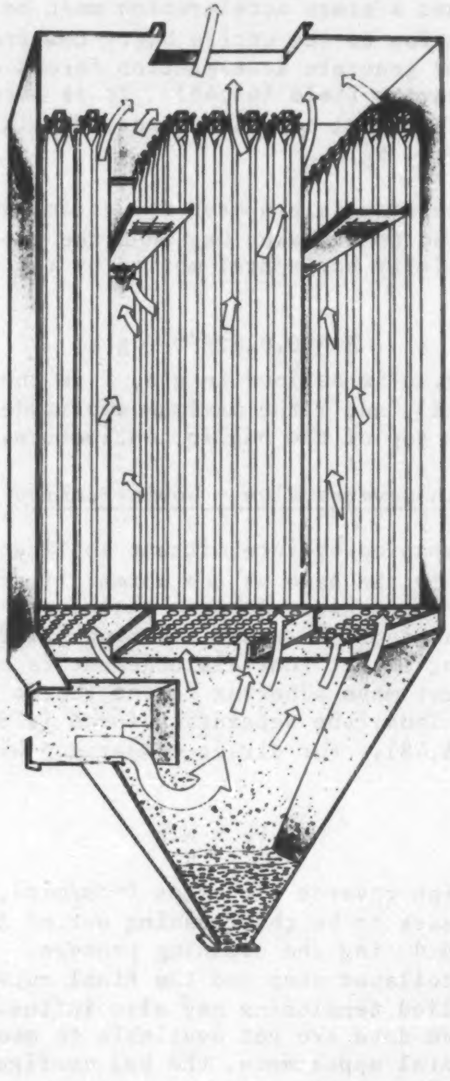


Figure 16. Cutaway view of a shaker baghouse (courtesy of MikroPul Corp.--excerpt from Bulletin TSQ-1).

The acceleration is computed from shaker arm amplitude (displacement from center position) and shaking frequency, Equation (2-27). Field and laboratory tests have indicated that average acceleration must be at least 3 g's to transmit the shaking motion to the entire bag. Low frequencies (<4 cps) and small amplitudes (<1 cm) generate acceleration forces appreciably less than that attainable in a gravity field (46,48). It is assumed that at the instant of dust dislodgement, the local adhesive force, F_A, is only slightly less than the separating force, F_S.

The following expression is proposed for estimating the average acceleration, $\bar{a}$, imparted to a shaken bag when the top of the bag is oscillated in an essentially horizontal motion by the shaker arm (46,48,49).

$$\bar{a} = 0.0282 f^2 Y = g's \qquad (2\text{-}27)$$

In Equation (2-27), a is defined in g's, f is the shaking frequency in cycles per second (Hertz), and Y the maximum amplitude (displacement from center position) of the top of the bag in centimeters.

2.7.2 Bag Collapse With Reverse Flow - Woven Fabrics (48,49,121)

Bag collapse accompanied by intermittent application of low velocity, reverse air flow (roughly the same as the normal filtration flow) is a preferred method of cleaning glass fabrics because it avoids the stresses caused by mechanical shaking. Here the cleaning principle is essentially the same as that for shaking except that dislodgement is produced by the shearing force created by the dust mass adhering to the fabric and the downward pull of the gravity field, g. Thus, the separation force is defined by the product W.g rather than W.a (46,48). For direct comparison with the mechanical shaking relationships,

$$F_S = W.g \qquad (2\text{-}28)$$

Except for unusually high reverse air rates (~3m/min), the principal function of the reverse air appears to be the flushing out of fine dust particles removed and/or loosened during the cleaning process. The rate at which the bag flexes during the collapse step and the final curvature assumed by the bag depending upon the applied tensioning may also influence dust removal, although no quantitative data are yet available to measure such effects (123). In general appearance, the bag configurations, methods of bag attachment to the compartment tube sheet, and overhead suspensions are similar to those used with mechanical shaking systems. Commercial baghouse designs are shown in Figures 17 and 18, and various suspension and bag tensioning approaches are illustrated in Figure 19.

2.7.3 Pulse Jet Cleaning - Felted Media (1,107,124-131)

Despite the sharing of many design and operating features with the previously discussed reverse flow (RF) or mechanically cleaned (MC) systems, including the general arrangement of filter tubes as shown in Figures 20 and 21, several unique aspects of pulse jet-cleaned felts warrant separate treatment. First, from the design perspective, pulse jet filters are intended

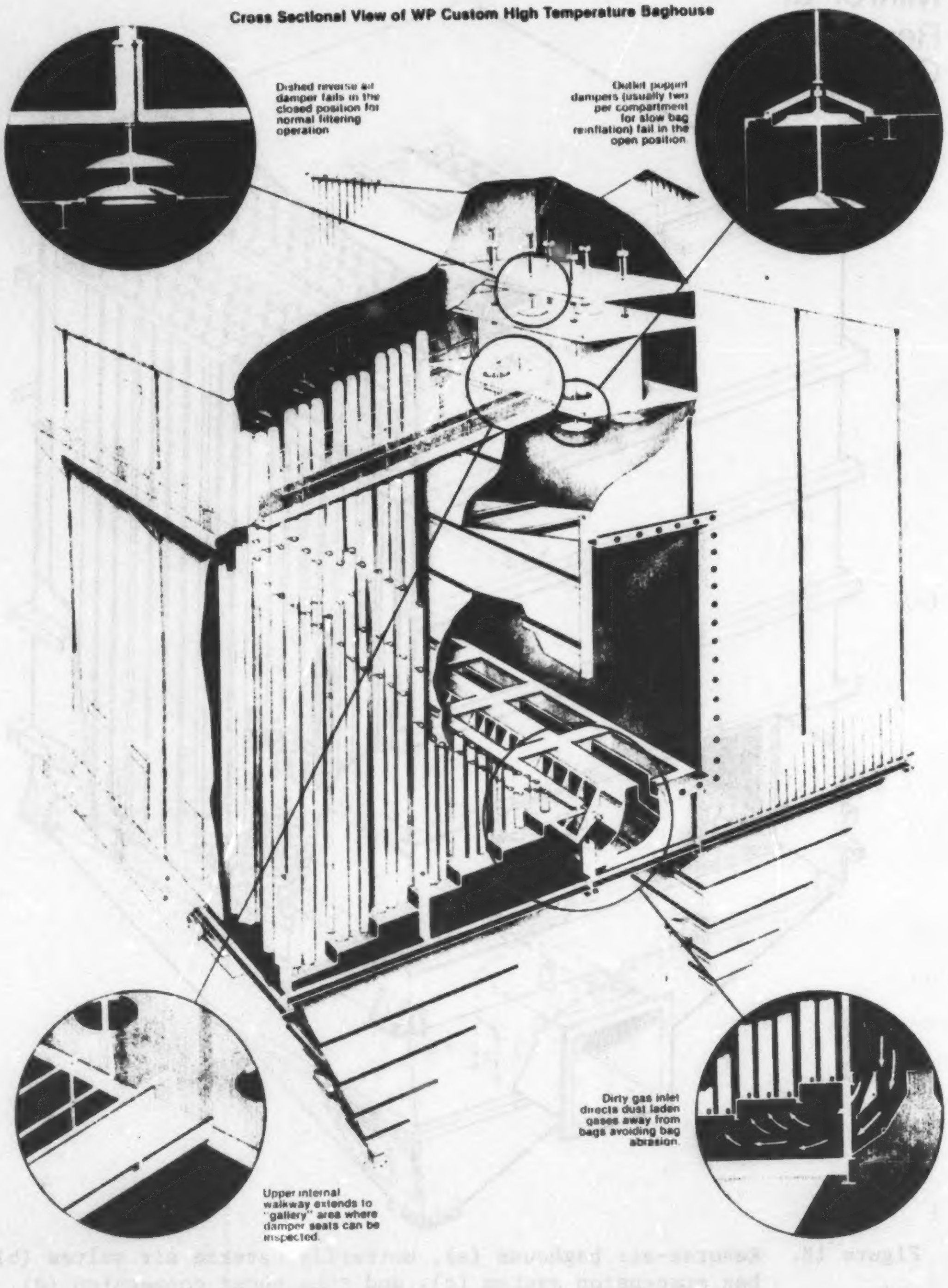

Cross Sectional View of WP Custom High Temperature Baghouse
Dished reverse air damper fails in the closed position for normal filtering operation
Outlet poppet dampers (usually two per compartment for slow bag reinflation) fail in the open position
Dirty gas inlet directs dust laden gases away from bags avoiding bag abrasion
Upper internal walkway extends to "gallery" area where damper seats can be inspected

Figure 17. Reverse air baghouse (courtesy of Joy Industrial Equipment Co.--Western Precipitation Division).

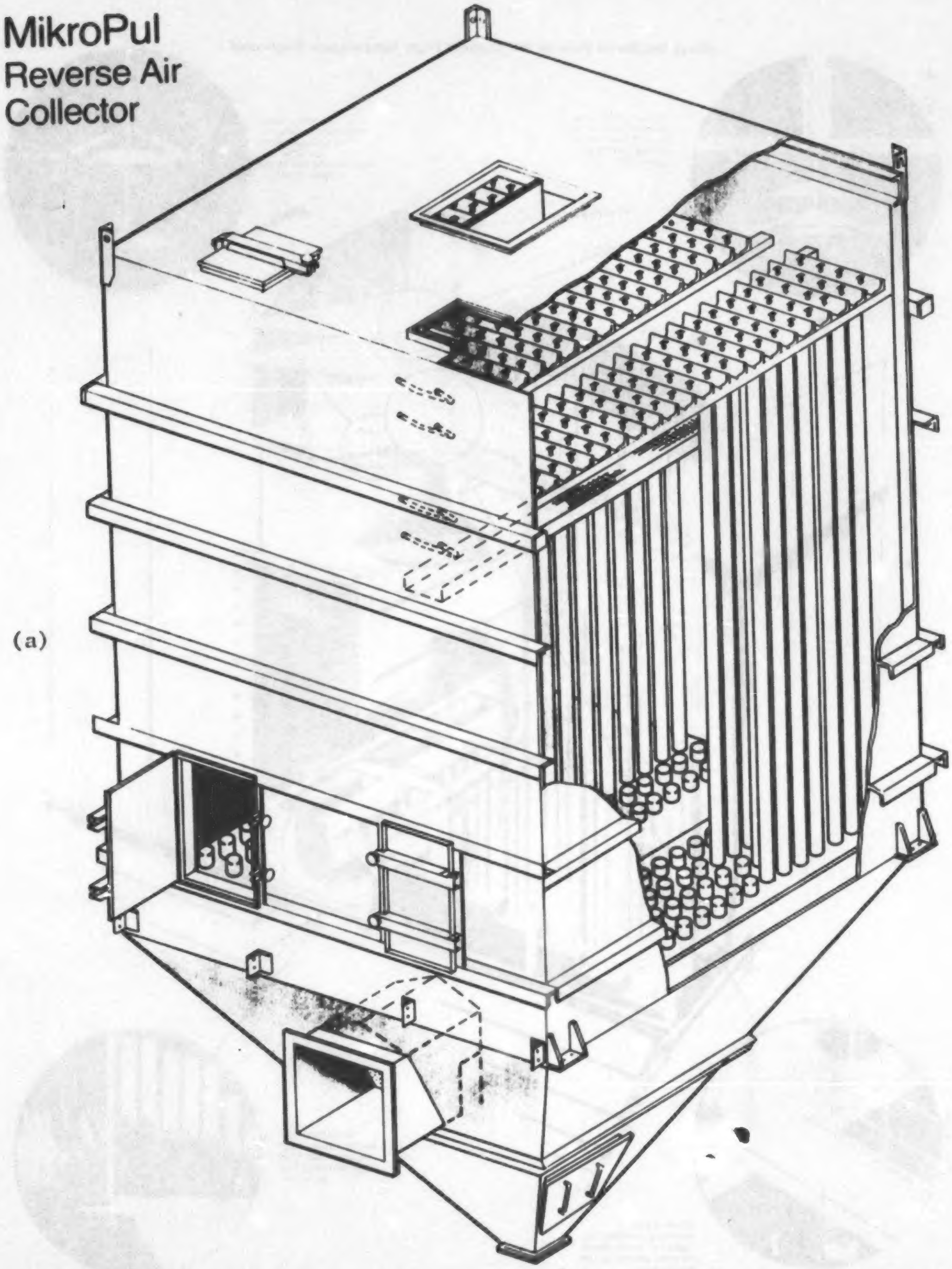

MikroPul
Reverse Air
Collector
(a)

Figure 18. Reverse-air baghouse (a), butterfly reverse air valves (b), bag suspension system (c), and tube sheet connection (d). (Courtesy of MikroPul Corp.--excerpt from Bulletin TSQ-1).

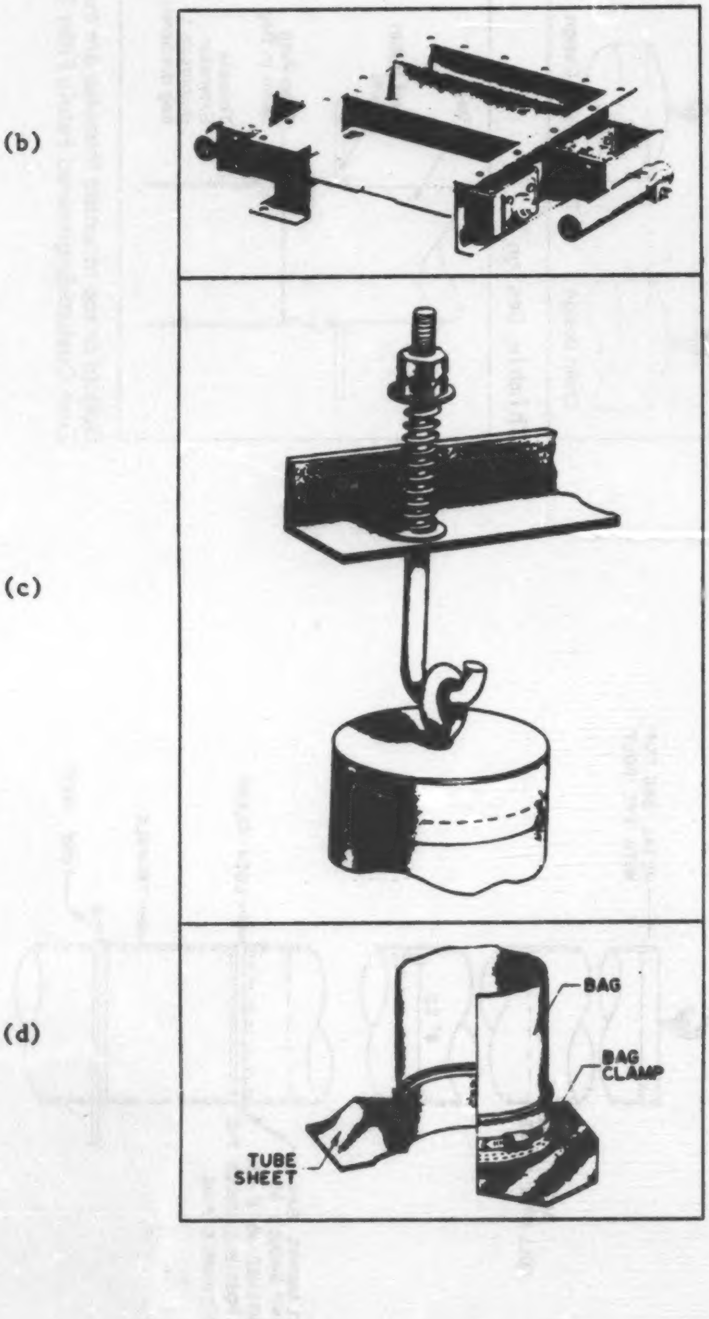
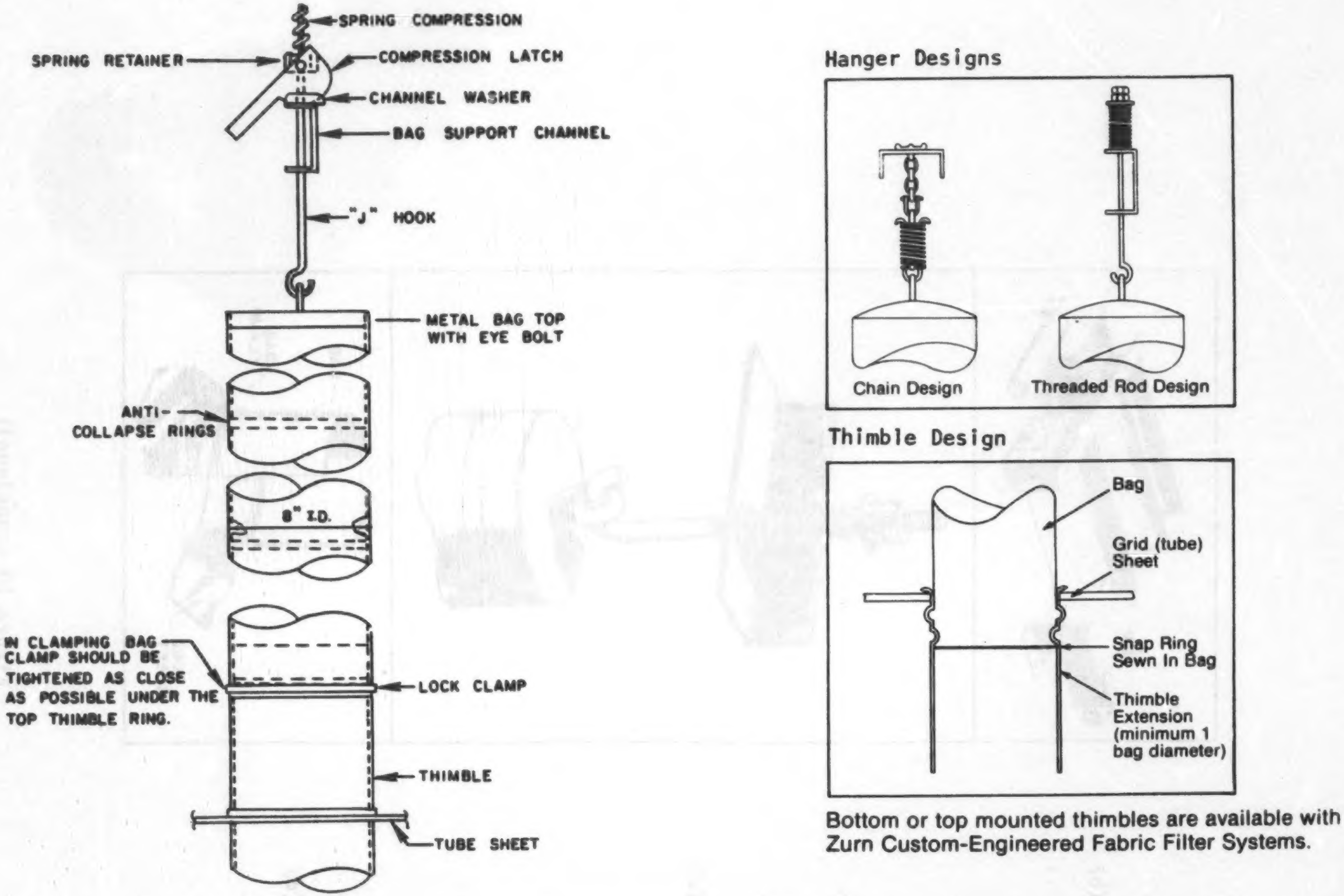

(b)
(c)
(d)
BAG
BAG CLAMP
TUBE SHEET

Figure 18 (continued)


SPRING COMPRESSION
SPRING RETAINER
COMPRESSION LATCH
CHANNEL WASHER
BAG SUPPORT CHANNEL
"J" HOOK
METAL BAG TOP WITH EYE BOLT
ANTI-COLLAPSE RINGS
8" I.D.
IN CLAMPING BAG CLAMP SHOULD BE TIGHTENED AS CLOSE AS POSSIBLE UNDER THE TOP THIMBLE RING.
LOCK CLAMP
THIMBLE
TUBE SHEET
Hanger Designs
Chain Design
Threaded Rod Design
Thimble Design
Bag
Grid (tube) Sheet
Snap Ring Sewn In Bag
Thimble Extension (minimum 1 bag diameter)

Bottom or top mounted thimbles are available with Zurn Custom-Engineered Fabric Filter Systems.

Figure 19. Typical bag suspension systems for reverse-air baghouses (courtesy of Zurn Industries, Inc., Air Systems Division--excerpts from reverse-air baghouse operation and maintenance manual and Form No. 422-ADV 5M),

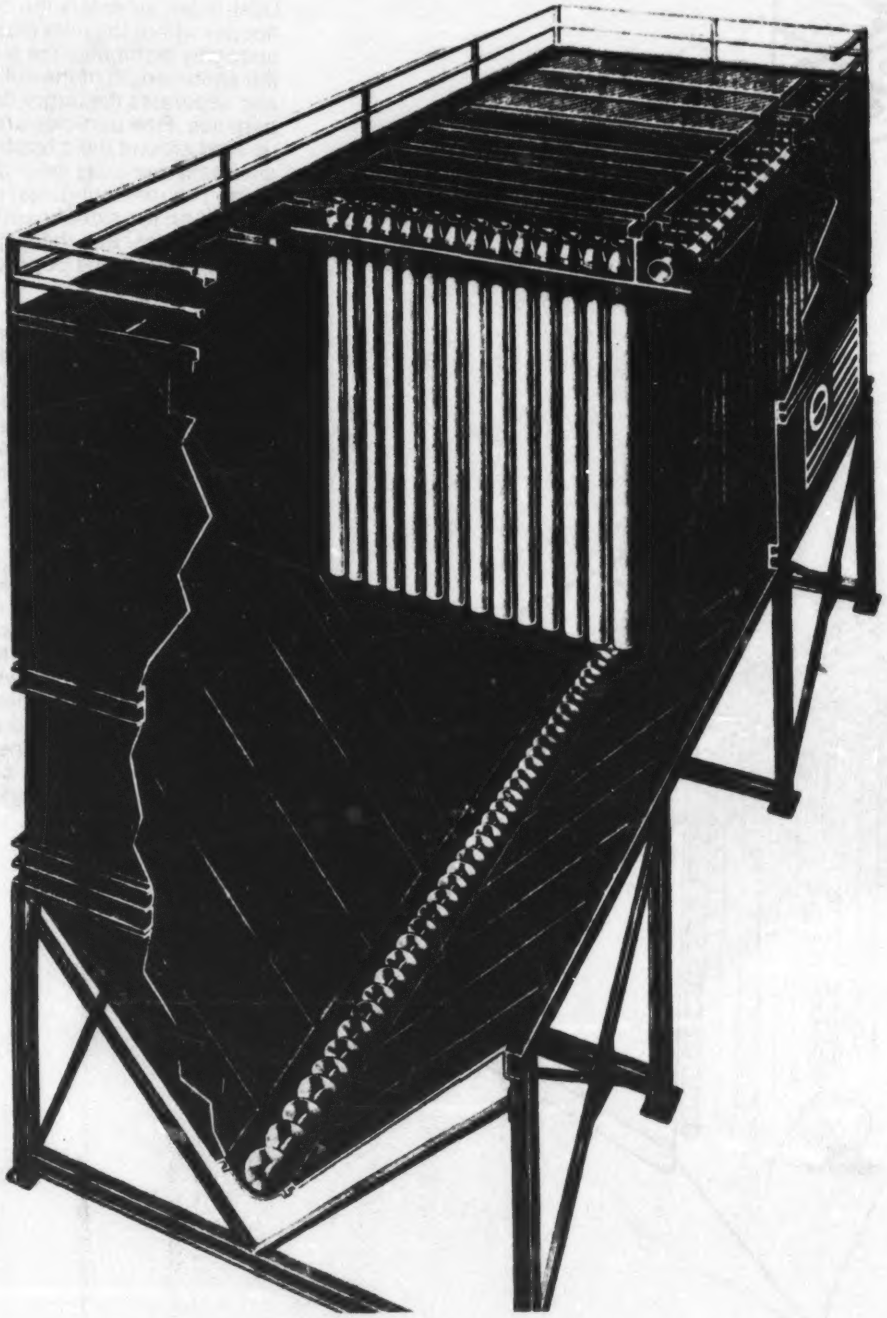


Figure 20. Cutaway view of an Alpha Series Pulse-Jet Baghouse (courtesy of Standard Havens, Inc.).

HOW IT WORKS

Dust-laden air enters the collector hopper where the inlet classifier uniformly distributes the air through the entire length of the collector and separates the larger dust particles. Fine particles are borne upward around the classifier by the airstream and pass around the filter bags. The remaining dust is deposited on the exterior surface of the filter bags, and the clean gas passes through the bags to the outlet manifold.

Once a uniform layer of dust has been deposited on the filter bag surface, it is removed on a predetermined cycle by a high pressure pulse of compressed air. In each cycle only one row of filter bags is pulsed at a time; the frequency and duration of the pulse is determined by actual field conditions. The ENELCO venturi provides for a two-stage cleaning effect. The venturi shapes the initial pulse of air to provide an air mass which moves down the filter bag tube, expanding the bag and dislodging the dust from the outer surface. The motion of the compressed air draws some secondary plenum air behind it, adding to the downward air wave. The downward flow helps propel dust to the hopper and provides for backwashing of the bags to remove deeply imbedded dust.

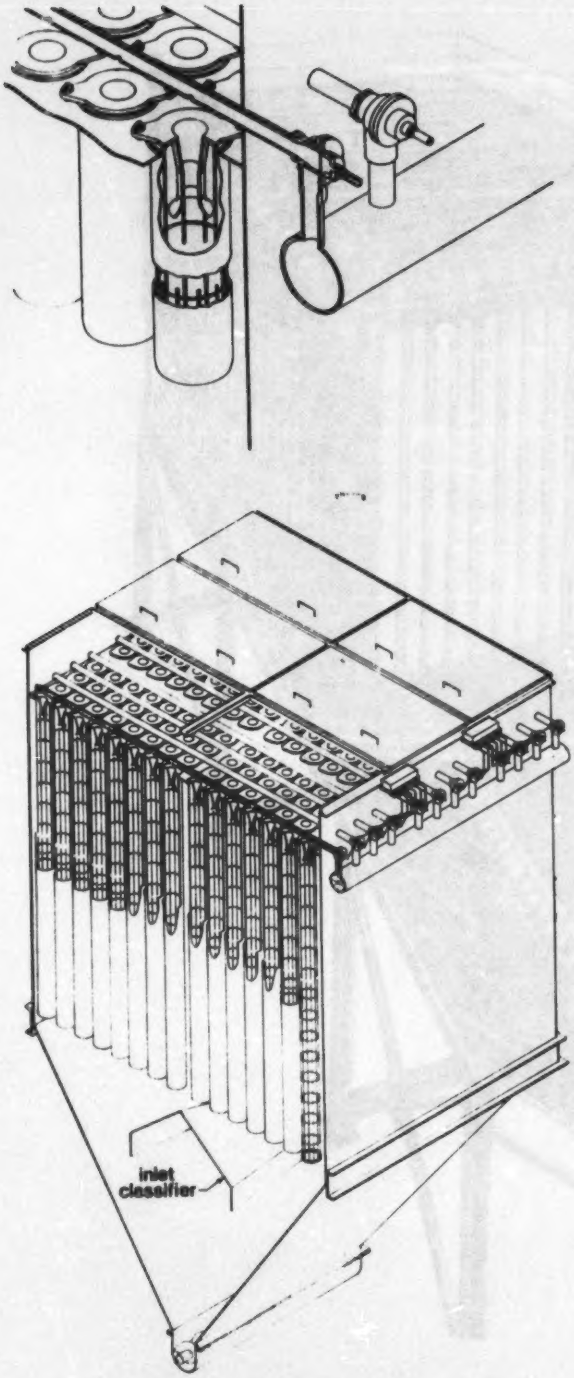


Figure 21. Schematic of pulse-jet baghouse and compressed air header (courtesy of Environmental Elements Corp.--excerpt from Form 973 DV 15M).

to operate at higher filtration velocities, ~3 m/min (10 fpm) than those used with woven fabrics, ~1 m/min (3 fpm) and with a narrower range of operating pressure loss. The resulting advantages are a decreased space requirement and less variation in gas flow, although higher operating costs and lower efficiencies may appear on the debit side (133). Second, although fabric cleaning is again accomplished by the separating (tensile) force produced by fabric and dust acceleration, the intensity, and, in particular, the brevity of the cleaning process (~0.1 second) preclude direct use of the mathematical relationships proposed for woven fabric RF or MC systems (128,132).

Because of the stiffness of most felts, conventional mechanical shaking is insufficient to create the bag motion needed to clean the fabric. (1,107,128) Additionally, the typical 3- to 4-fold increase in filtration velocity requires very frequent and intense cleaning to remove the collected dust. In most cases, not only would mechanical shaking fail to keep up with the dust deposition, but the felted medium itself would also be subject to damage due to repeated stretching action (107).

2.7.3.1 Qualitative Description of Pulse Jet Filtration--

The filter medium ordinarily consists of an open top felt tube supported by an interior wire cage so that outside-to-inside air flow is possible without tube collapse (see Figure 22) (1,4,7,28,107,127-132). With this arrangement, dust deposition takes place on the outside rather than the inside fabric surface as found with the previously discussed MC and RF systems. When the pressure gradient across a compartment housing several tubes reaches some preset limit, the tubes undergo sequential cleaning either on a "one tube at a time basis" or on a "row by row basis" wherein several tubes are cleaned (pulsed) simultaneously. In some cases, a simple timing circuit is used to activate the cleaning.

The cleaning process consists of the introduction of a high pressure (~90 psig) reverse air pulse at the top (exit) end of the tube. Because the pulse duration is very brief (~0.1 second), there is no "effective" isolation of tubes or compartments such as that encountered with woven fabrics where off-line times may be as much as 5 minutes (1,107,126,132) . Rapid tube inflation accelerates the tube and dust in a radial direction which causes the dislodgement of surface dust deposits in the form of coarse agglomerates. Although the mass of the dislodged dust may be large, only a very small fraction (~1 to 10 percent) actually descends to the dust hopper because gas flow resumes in about 0.1 second (107,128,130-132). At steady state operation, the amount of dust falling to the dust hopper per tube will be equal to the amount of dust deposited on the tube during the preceding filtration period (time between pulses). What distinguishes the pulse jet cleaning process from simple reverse flow or mechanical cleaning is that most dust dislodged by the jet pulse is returned to the felt surface; all dust removed from woven fabric RF and MC systems has sufficient settling time (2 to 5 minutes) to fall to the dust hopper (107). Additionally, the K_2 values for successive dust deposits will remain the same regardless of cake depth, although the cake depth itself may vary from point to point (107,128,132).

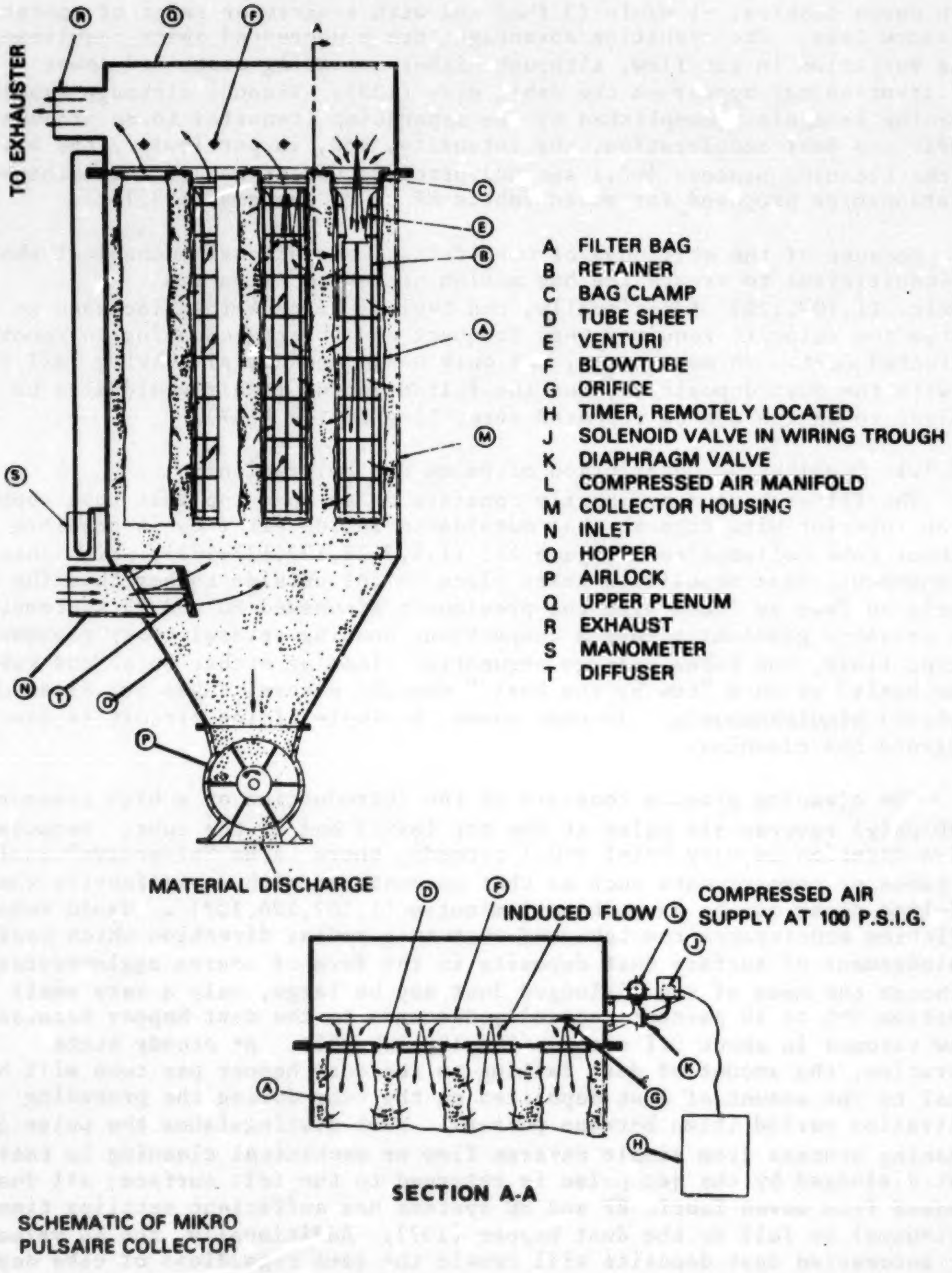

TO EXHAUSTER
R
D
F
C
E
B
A
M
S
N
T
O
P
MATERIAL DISCHARGE
A FILTER BAG
B RETAINER
C BAG CLAMP
D TUBE SHEET
E VENTURI
F BLOWTUBE
G ORIFICE
H TIMER, REMOTELY LOCATED
J SOLENOID VALVE IN WIRING TROUGH
K DIAPHRAGM VALVE
L COMPRESSED AIR MANIFOLD
M COLLECTOR HOUSING
N INLET
O HOPPER
P AIRLOCK
Q UPPER PLENUM
R EXHAUST
S MANOMETER
T DIFFUSER
INDUCED FLOW
COMPRESSED AIR SUPPLY AT 100 P.S.I.G.
L
J
K
G
H
SECTION A-A
SCHEMATIC OF MIKRO PULSAIRE COLLECTOR

Figure 22. Schematic of Mikro-Pulsaire dry dust collector and operating components (courtesy of MikroPul Corp.--excerpt from Owners Manual SD 379A).

In the case of pulse jet filters, 90 to 99 percent of the dislodged dust redeposits as a uniformly distributed layer, but with a significantly lower K_2 value than that of a fresh dust deposit because of its highly agglomerated state (128,132). The specific resistance for the redeposited layer, has been assigned the symbol $(K_2)_c$ (128). Although the jet pulse has the capability to dislodge the dust deposits, there is only sufficient energy transfer to accomplish a partial breakup of the dust such that the suspension consists mainly of agglomerates (128-132). Therefore, when filtration resumes for periods varying from 1 to several minutes, a new layer of dust deposits on top of the underlying or "cycling" layer, W_c. The new layer displays the characteristics of the freshly deposited dust and hence a higher K_2 value because it is composed mainly of discrete rather than agglomerated particles.

2.7.3.2 Estimation of Pressure Loss - Theory--

Since the above concepts provided a rational description of the pulse jet filtration process, it has been proposed that the overall filter pressure loss, P, be computed as shown below (128).

$$P = P_E + (K_2)_c \; V \; W_c + K_2 \; V \; W \qquad (2\text{-}29)$$

Equation (2-29) states that overall filter pressure loss for a single tube over the filtration interval t is the algebraic sum of the contribution from the conditioned felt, P_E; the resistance offered by the cycling layer, W_c, with its low $(K_2)_c$ value; and the pressure loss due to the most recent or overlying dust deposit with its normal K_2 value. The term W is expressed by the same relationship used for woven fabric RF or MC systems (1,107); i.e.,

$$W = C_i \Delta V \; t, \qquad (2\text{-}30)$$

where Δt represents the filtration interval between pulses.

The first and the third right hand members of Equation (2-29) are identical to those appearing in Equation (2-17) for woven fabric filters whereas the second term is peculiar to pulse jet systems. It is expected that the pressure loss contributed by the cleaned felt, P_E, will increase gradually with time as more and more dust becomes irreversibly embedded in the fiber structure (1,107,128,132). Except for special experimental measurements, the quantity W_c is usually undefined and only estimated values of $(K_2)_c$ have been reported (128). Thus, Equation (2-29), although constituting a logical model for pulse jet filtration, cannot as yet be used for predictive purposes. However, because the dust layer is projected from the fabric as a result of the compressed air pulse, one can infer that the interaction between tensile and adhesive forces (134-136) again determines the amount of fabric cleaning attained. Additionally, it is also reasonable to assume that the greater the intensity of the compressed air pulse, (as defined by its pressure level and volume delivery) the more effective the cleaning (126-132).

2.7.3.3 Equilibrium Pressure Losses--

Reference to Equation (2-29) shows that for a fixed inlet velocity and dust concentration, any reduction in pressure loss must depend upon corresponding reductions in the terms W_c and W. Qualitatively, increased pulse pressures, P_j, lead to decreased W_c values (up to a point), whereas W can be decreased only by reducing the interval between successive jet pulses (unless inlet concentration and/or filtration velocity are reduced). Based upon laboratory observations, it appears that the quantity $(W_c + W)$ is uniquely determined by the adhesive properties of the specific dust-fabric combination and the cleaning energy imparted by the jet pulse (107,128,132). For this reason, a pulse jet system can operate within relatively narrow pressure loss boundaries for a fixed cleaning regimen despite significant variations in inlet dust loading. Although pressure loss necessarily increases with velocity, the W_c portion of the total removable fabric loading does not vary significantly unless the reservoir (and pulse) pressure, P_j, change, see Table 9 (107).

2.7.4 Dust Removal versus Cleaning Method

At the present time, there are no theoretical means to determine how much dust will be dislodged during cleaning despite the fact that rational (if not accurate) estimates of the separating forces can be made. The principal difficulty is that again there is no method short of direct measurement to determine the adhesive forces at the interface between the dust layer and the fabric surface (134-136). As stated earlier, cleaning of woven fabrics is associated with a characteristic separation of the dust layer at the dust-fabric interface where adhesive bonds are normally the weakest (1,46,48,107). The resulting "cleaned areas" (see Figure 12), possess nearly identical "effective" residual drag properties, a fact that enables a realistic physical description of field filtration processes, provided that the degree of cleaning defined by the parameter, a_c, can be related to the cleaning energy input (46,48,49).

2.7.4.1 Fractional Cleaning, a_c, with Mechanical Shaking--

Limited experimental data are now available for specific dust/fabric combinations based upon bench scale and pilot measurements that show the relationship between the cleaning parameter, a_c, and fabric dust loading or the estimated adhesive force (see Figure 23) (46,48,49). The horizontal axis shows the actual, uniformly-distributed fabric loadings at the start of cleaning. The upper scale represents the computed adhesive force based on the estimated average acceleration for the indicated dust/fabric system. Note that fractional cleaned area, a_c, also describes that fraction of the fabric surface where the adhesive forces must be smaller than the separating forces produced by the cleaning action.

The development of fractional cleaning concepts discussed here is based upon the assumption that dust dislodgement takes place as an interfacial separation. Although laboratory and limited field observations have confirmed the above phenomenon, it is important to note that long-term, moisture condensation coupled with chemical reactions may alter the "ideal" separation process. Recent field observations suggest that dust may also spall off as a superficial layer leaving part of the surface layer behind. (138) Protruding fibers or excess nap also contribute to incomplete cleaning.

TABLE 9. SUMMARY DATA - EFFECT OF RESERVOIR PRESSURE, FACE VELOCITY, AND INLET FLY ASH CONCENTRATION ON RESIDUAL FABRIC LOADING AND AVERAGE PRESSURE LOSS[a]

	$C = 2.0\ g/m^3$ $V = 2.6\ m/min$		$C = 26.5\ g/m^3$ $V = 2.6\ m/min$		$C = 22.7\ g/m^3$ $V = 1.89\ m/min$	
Reservoir pressure psig (kPa)	Fabric dust loading g/m^2	Pressure loss, average-kPa	Fabric dust loading g/m^2	Pressure loss, average-kPa	Fabric dust loading g/m^2	Pressure loss, average-kPa
40 (276)	405	1.620	549	1.600	503	1.170 (1.620)[b]
70 (483)	366	1.250	389	1.330	423	1.100 (1.520)[b]
100 (690)	373	0.750	382	1.230	439	0.950 (1.300)[b]

[a] Data excerpted from Tables 22 and 25, Reference (107)

[b] Pressure loss adjusted to 2.6 m/min with same fabric loading.

NOTE: Pulse duration = 0.06 sec, pulse interval = 1 min (damped pulse).

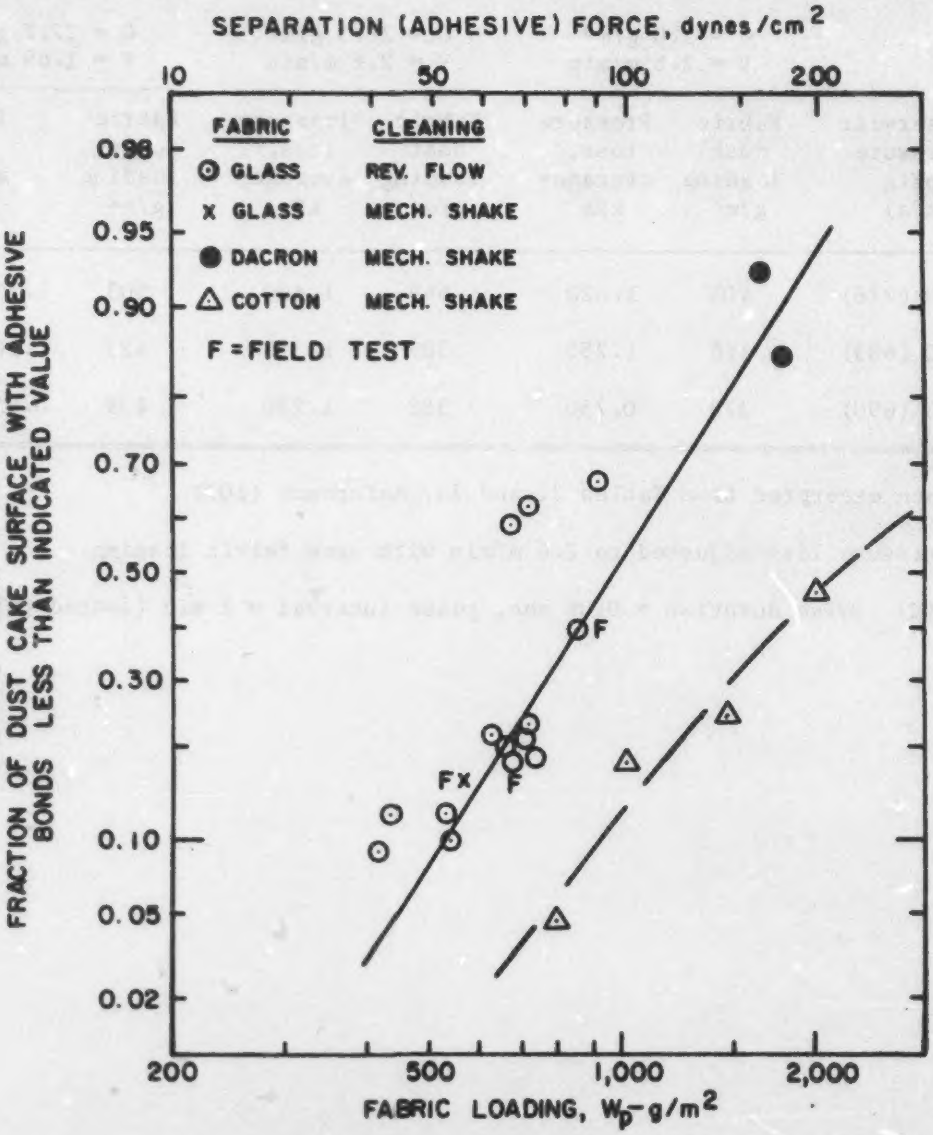


Figure 23. Cleaning levels attained for coal fly ash (MMD = 7μm) with several fabrics as a function of fabric loading and/or estimated separating (adhesive) force.

When the fabric is cleaned by mechanical shaking, the cleaning parameter for a coal fly ash/woven glass fabric system may be estimated from the following equation (46,48,49,107):

$$a_c = 2.23 \times 10^{-12} (f^2 A_s W_p')^{2.52} \qquad (2\text{-}31)$$

The term W_p' (g/m^2), which appears in both Equations (2-31) and (2-32), designates the average fabric loading immediately before initiation of cleaning. In most field applications, it is usually impossible to determine the magnitude of W_p' by any direct measurement. However, it is possible to calculate a_c by a mathematical process carried out within the predictive model described in References 46, 48, 49, 100 and highlighted in Appendix F, provided that the following information is available: (a) baghouse design and operating parameters usually defined in the course of routine compliance or acceptance tests, and (b) estimated values for K_2 and S_E.

2.7.4.2 Fractional Cleaning with Bag Collapse and Reverse Flow--

For coal fly ash/woven glass fabric systems cleaned by collapse and reverse flow, the cleaning parameter, a_c, may be computed from Equation (2-32) (48),

$$a_c = 1.51 \times 10^{-8} W_p', \qquad (2\text{-}32)$$

where W_p' is the average fabric dust loading (g/m^2) at the time when cleaning is initiated. Reference to Figure 23 indicates that fly ash particles ~7 μm MMD show much greater adhesion with a cotton fabric because of the larger number of free fibers (nap) at the dust/fabric interface (107). In the case of napped cotton, 100 percent of the fabric surface is covered with a loose fiber nap, whereas glass fabrics show about a 75 percent free fiber surface coverage. As a result, about 10 percent surface removal was attained with cotton as compared to nearly 50 percent with a woven glass fabric when the fabric loading was 1,000 g/m^2 (see Figure 23). Because cotton fabric can withstand vigorous shaking, however, adequate cleaning is still attainable despite the increased adhesion factor.

As stated earlier, collapse and reverse flow cleaning is generally less effective than mechanical shaking (~5 to 35 versus ~50 percent with the latter method). On the other hand, the former approach permits the use of heat resistant glass fabrics that might otherwise fail under vigorous shaking conditions.

2.7.4.3 Effective Filter Cleaning by Pulse Jet Air--

It has been observed that the high energy shocks imparted to a felted fabric are sufficient to completely remove the overlying or surface dust layer with a properly designed system (107). Therefore, the cleaning parameter, a_c, although not used for modeling pulse jet filtration, would automatically assume a value of one (128,132). On the other hand, any working equation for predicting pressure losses for a pulse jet system must take into account the redeposition of most of the dislodged dust that results in a unique recycling layer, W_c, with its unique specific resistance coefficient, $(K_2)_c$ (128,132). Because there now exists no way to compute these terms directly, filter pressure loss must be estimated by a combination of empirical relationships based upon limited experimental data.

The single bag test results shown in Figures 24 and 25 provide useful guidelines for fly ash and talc filtration with a needled Dacron felt (107,132). The term "damped pulse" applies to an experimental modification of commercially available equipment that permits a gradual rather than an abrupt deflation of the tube when the pulse flow ceases (107,129,132). The advantage of this procedure is that elimination of the "snap" as the tube returns to its normal filtration position greatly reduces (up to 5 times) the outlet dust concentration.

The information obtainable from Figures 24 and 25 may be used to develop a modified form of Equation (2-29) that allows the filter user to extrapolate from one set of operating pressures to another. First, the terms P_E and $(K_2)_c VW_c$ may be consolidated to describe the "effective" residual pressure loss, $(P_E)_{\Delta W}$ at the cessation of the jet pulse (and at the resumption of filtration). Hence total pressure loss, P, is then expressible by the following equation (128,132):

$$P = (P_E)_{\Delta W} + K_2 V^2 C_i \Delta t \qquad (2\text{-}33)$$

The slopes of the curves reflect the freshly deposited K_2 values for the two dusts at the designated filtration velocity while their vertical displacements result from differences in the intensity and type of the pressure pulses. It is emphasized, however, that any working relationship deriving from Figures 24 and 25 such as Equation (2-33) is restricted to 4 ft long (1.22 m) by 4 1/2 in. diameter (11.4 cm) bags and a jet nozzle with a true inside diameter of 0.363 in. (0.92 cm). In a subsequent paper, however, Dennis et al (132). have proposed a set of general equations that take into account both the volume of compressed air pumped into a bag over a specified time interval and the volume of the bag itself. The latter data enable computation of the rate at which the bag pressure increases, d p/dt, a parameter necessary to define the energy input to the dust-laden bag. The term $d(\Delta p)/dt$, (kPa/s) is defined by the relationship:

$$d(\Delta p)/dt = 211\, P_{ja}\, A_j/V_b \qquad (2\text{-}34)$$

where P_{ja} is the absolute pulse jet reservoir pressure (kPa), A_j is the true jet nozzle cross section (m^2), and V_b the volume of the filter bag (m^3). Ambient sea level pressure and temperature are assumed along with a nominal 0.01 second opening time for the solenoid valves customarily used in pulse jet equipment. Related analyses have shown that the residual effective pressure $(P_E)_{\Delta W}$, (kPa) can also be estimated from Equation (2-35), the latter based on data graphed in Figure 26.

$$(P_E)_{\Delta W} = 1{,}600\, [d(\Delta p)/dt]^{-1.13} \qquad (2\text{-}35)$$

Therefore, the total filter pressure loss, P, in kPa based upon a combination of Equations (2-33) through (2-35) is calculated as:

$$P = 1{,}600\, [211\, P_{ja}\, A_j/V_b]^{-1.13} + 0.001\, K_2 V^2 t \qquad (2\text{-}36)$$

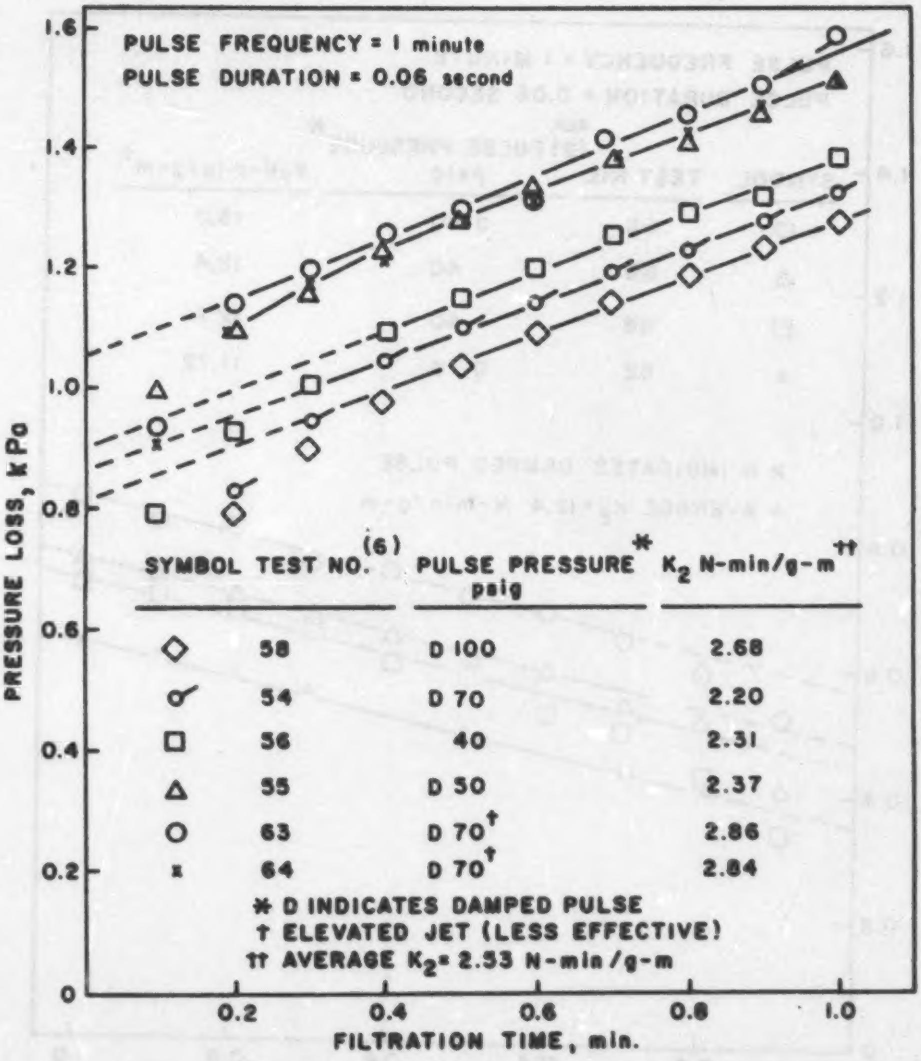


Figure 24. Resistance characteristics and K_2 values for fly ash and Dacron felt, inlet concentration 27.6 g/m, filtration velocity 2.6 m/min.

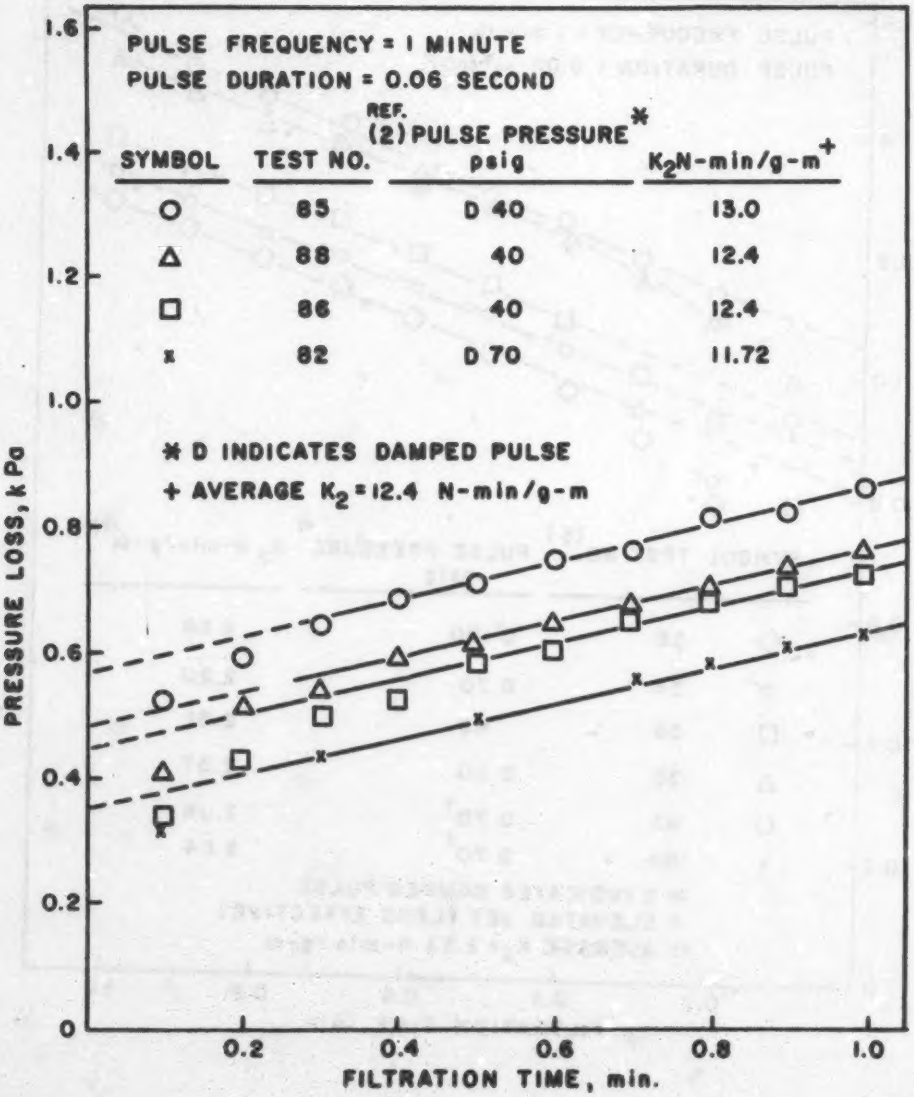


Figure 25. Resistance characteristics and K_2 values for talc with dacron felt, inlet concentration 3.5 g/m^3, filtration velocity 2.6 m/min.

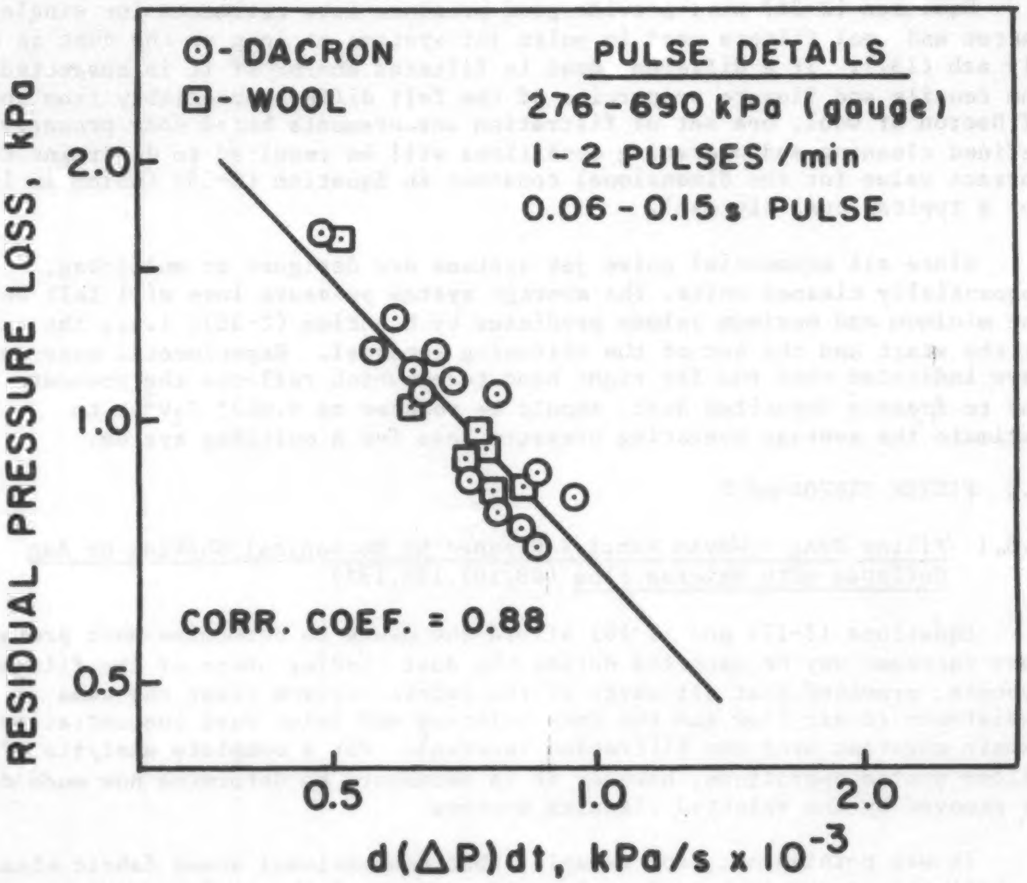


Figure 26. Effective residual pressure loss versus d(Δp)/dt, 0 to 0.01 S. Fly ash filtration at 2.6 m/min.

where K_2 is the best estimate of the specific resistance coefficient for the freshly deposited dust (N-min/g-m), V the filtration velocity (m/min), and Δt the filtration time between pulses per bag (min).

Equation (2-36) will provide good pressure loss estimates for single bag Dacron and wool filters used in pulse jet systems so long as the dust is coal fly ash (132). If a different dust is filtered and/or if it is suspected that the tensile and flexure properties of the felt differ appreciably from those of Dacron or wool, one set of filtration measurements based upon properly defined cleaning and operating conditions will be required to determine the correct value for the dimensional constant in Equation (2-35) (which is 1,600 for a typical coal fly ash).

Since all commercial pulse jet systems are designed as multi-bag, sequentially cleaned units, the average system pressure loss will fall between the minimum and maximum values predicted by Equation (2-36); i.e., the values at the start and the end of the filtering interval. Experimental measurements have indicated that the far right hand term, which reflects the pressure loss due to freshly deposited dust, should be reduced to $0.0075\ K_2V^2\Delta t$ to estimate the average operating pressure loss for a multibag system.

2.8 FILTER PERFORMANCE

2.8.1 Filter Drag - Woven Fabrics Cleaned by Mechanical Shaking or Bag Collapse with Reverse Flow (48,107,128,132)

Equations (2-17) and (2-18) afford the means to determine what pressure loss increase may be expected during the dust loading phase of the filtration process, provided that all parts of the fabric surface offer the same resistance to air flow and the face velocity and inlet dust concentration remain constant over the filtration interval. For a complete analysis of filter system operations, however it is necessary to determine how much dust is removed by the selected cleaning process.

It wes pointed out, for example, that conventional woven fabric cleaning techniques remove anywhere from 5 to 50 percent of the surface dust layer (42,46,49,107). As a result, resumption of filtration produced a family of S-W curves shown in Figure 12 where very striking differences in filter drag were indicated for various degrees of partial cleaning despite the fact that average fabric loadings were identical. It has also been determined that all cleaned filter regions (bright areas in Figure 11) possess the same residual and effective drag characteristics, S_r and S_E, and that the uncleaned regions represent the state of the loaded fabric surface just before cleaning (46,48,49). Therefore, the instantaneous drag values for the overall filter, S, at the resumption of filtration on a partially cleaned surface are readily calculated by the following relationship (1,46,48,107,158-160):

$$S = \left(\frac{a_c}{S_c} + \frac{a_u}{S_u} \right)^{-1} \qquad (2\text{-}37)$$

where a_c and a_u indicate the cleaned and uncleaned fractions of the fabric surface, respectively; S_c is the drag for the cleaned areas that may also be approximated by S_E; and S_u is the drag for the uncleaned areas

(46.48,49). As pointed out earlier, the relationship implied by Equation (2-37) breaks down, if because of difficult cleaning conditions, the dust layers no longer separate at the fabric-dust cake interface region but at some point above the fabric surface. Equation (2-37) depicts the well established flow principle that, given alternative flow channels (the uncleaned and cleaned areas), the fluid automatically seeks the path of least resistance. Thus, the flow imbalance decreases with extended filtration until near-uniform velocity and fabric loading distributions are reestablished.

If the concept represented by Equation (2-37) is extended to a real filter system wherein, immediately following cleaning, there exists a specific fraction of just-cleaned surface, a_c, as well as several additional surface regions possessing varying degrees of dust cover, $a_{u_1}, a_{u_2} \ldots a_{u_i}$, the changes in overall filter drag for a multi-compartment system may then be described by the general relationship (46,48):

$$S = \left(\sum_{i=1}^{n} \frac{a_c}{S_c} + \frac{a_{u_1}}{S_{u_1}} \ldots \frac{a_{u_i}}{S_{u_i}} \right)^{-1} \qquad (2\text{-}38)$$

Since the mechanisms have already been established for calculating drag values for uniformly loaded fabric surfaces provided that K_2 and S_E have been determined, Equation (2-38) with the aid of a computer program becomes a workable tool for calculation of overall filter system drag.

The several relationships involved in the computation of filter system drag or pressure loss (in contrast to the simple equation used for single panel tests) apply equally well to any woven fabric provided that the K_2 and S_E values for the dust of interest have been determined. The basic equations discussed in this section have been incorporated in the predictive filter model described in References 46, 48, 49, 100 and discussed briefly in Appendix F in a workable format for use by the field engineer in assessing (a) the feasibility of proposed operating procedures, or (b) the likelihood that existing equipment and operating modes will enable compliance with emissions regulations.

2.8.2 Dust Penetration - Woven Fabrics (1-8,28-31,47-49,94,95,104,107,121, 125,128-132)

2.8.2.1 Mass Emissions Rates--

In a previous section, it was pointed out that there is no easily applied theory for predicting the efficiency of a fabric filter despite the fact that the fundamentals of filtration are well understood. The performance of a fabric filter is governed by (a) the solidity and depth of the overlying dust layer (the latter constituting the true filtration medium), and (b) the physical properties of the underlying fabric that serves as the substrate for dust deposition (1,46-49,107).

If the dust cake is free from cracks, pinholes, or other defects, theory suggests that particle collection should be 100 percent for all practical purposes (42,46-49,107). However, fabric imperfections, whether they result from normal weave characteristics or from improper use or maintenance, can lead to cracks and/or perforations (pinhole leaks) in the dust layer.

2.8.2.2 Effect of Pinhole Leaks on Effluent Mass Concentration and Size Properties--

As stated in Section 2.2.6, any gas passing through pinholes in the fabric and/or the overlying dust layer carries with it most of its particulate loading (46-49). The reason for such penetration is that the actual pores are so large (~50 to 100 μm in the case of woven glass fabrics) that no diffusional capture is possible while the flow convergence in the leak region generates inertial forces that result in the capture of only the larger particles in the gas stream (>15 to 20 μm diameter). Since dust penetration through pinhole leaks may constitute 99 percent or more of total emissions with woven glass or similar fabrics, the size properties of many filter effluents can be characterized by those of the upstream particles.

In the case of the more efficient fabrics like sateen weave cotton, some reduction in particle size may result during the filtration process (47). However, the low order emission caused by gradual seepage of dust through a fabric will contribute small but measurable emissions even in the case of cotton, roughly 0.05 mg/m^3 as compared to 0.5 mg/m^3 with woven glass fabrics (46,48). At the present time, there is no reliable method for relating the particle size parameters of the upstream and downstream dust, regardless of the method of filtration. Despite attempts to define "characteristic" fractional particle size efficiencies for fabric filters, it is strongly advised that except for the "perfect replicate operation", no apparent fractional size parameters based upon measurements at one plant should be used to define effluent properties at another plant (150,153).

2.8.2.3 Effect of Filtration Velocity on Particulate Emissions--

There are few published guidelines for estimating the effect of filtration velocity on mass emission rates. Single particle-single fiber (collector) theory indicates that increasing velocity enhances particle capture by inertial impaction and decreases collection by diffusion mechanisms. Therefore, on a basis of mass efficiency, the fairly coarse particle sizes (>1 μm) found in most utility or industry-generated aerosols should be collected more efficiently at higher velocities.

However, because the particulate emissions from many fabric filters result from direct penetration through unbridged pores or gradual seepage, the effect of increased filtration velocity more often is to retard the closure of any openings in the fabric due to aerodynamic reentrainment and to accelerate the seepage rate, i.e., the gradual migration of dust through the fabric substrate to the clean air side (46-48,107,129,131,150).

Measured velocity effects for coal fly ash/glass fabric systems are shown in Figure 27 (46-48). It has been determined that outlet concentrations are so highly sensitive to filtration velocity that a 200-fold increase may occur as filtration velocities increase from 0.4 to 3.5 m/min (46,48). Since the

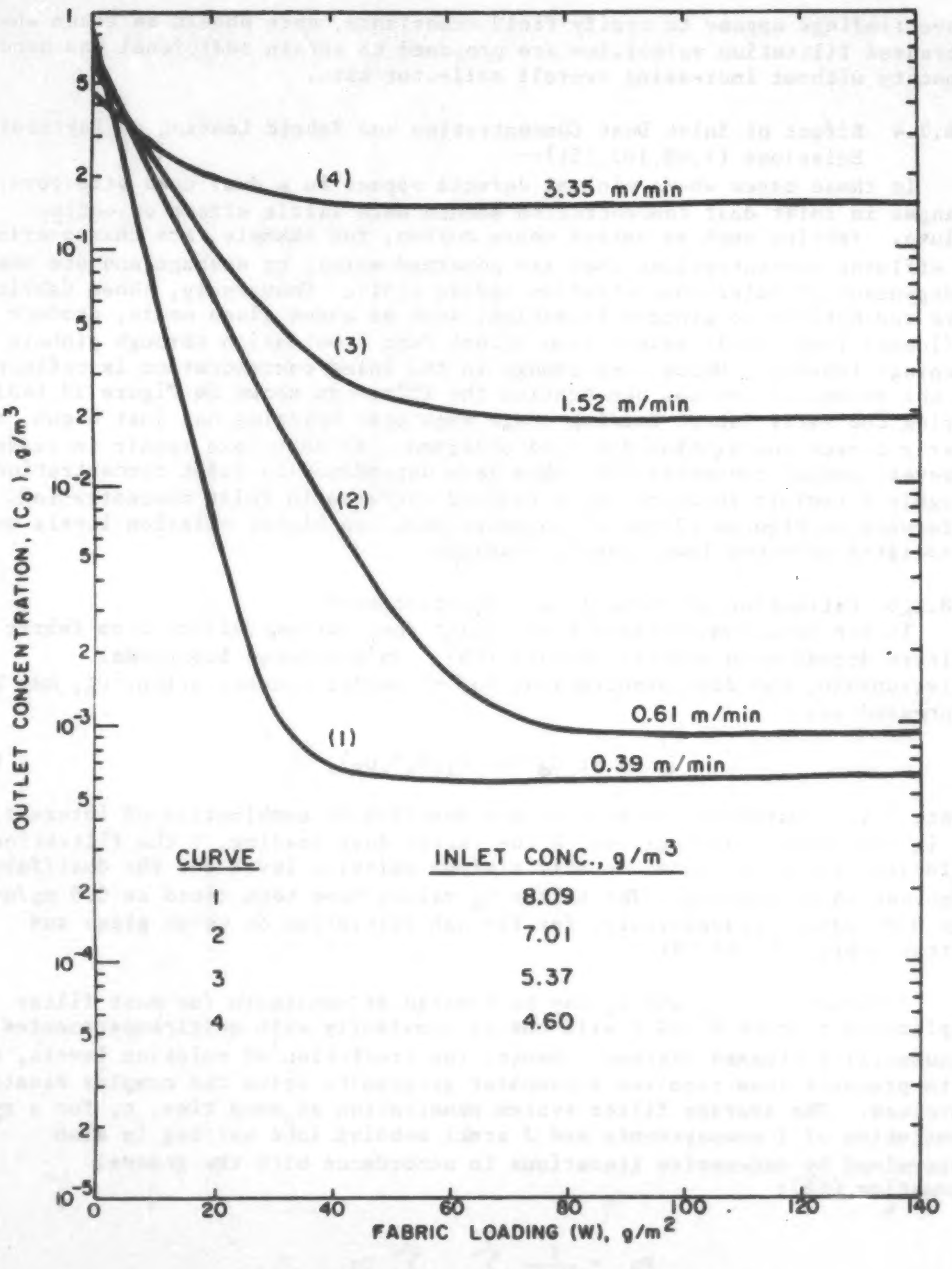


Figure 27. Observed outlet concentrations for bench scale tests with coal fly ash and woven glass fabrics as a function of fabric dust loading and filtration velocity.

above findings appear to typify field experience, care should be taken when increased filtration velocities are proposed to attain additional gas handling capacity without increasing overall collector size.

2.8.2.4 Effect of Inlet Dust Concentration and Fabric Loading on Particulate Emissions (1,48,107,151)--

In those cases where minimal defects appear in a dust cake structure, changes in inlet dust concentration should have little effect on outlet values. Fabrics such as sateen weave cotton, for example, are characterized by effluent concentrations that are governed mainly by seepage and are nearly independent of inlet concentration levels (151). Conversely, those fabrics more susceptible to pinhole formation, such as woven glass media, produce effluents that result mainly from direct dust penetration through pinhole openings (46-48). Hence, any change in the inlet concentration is reflected in the amount of aerosol penetrating the filter as shown in Figure 28 (48). During the early fabric loading stage when pore bridging has just begun, a nearly direct correlation has been observed. As dust cake repair increases, however, outlet concentrations show less dependency on inlet concentrations, roughly a twofold increase for a tenfold increase in inlet concentration. Reference to Figures 27 and 28 suggests that the higher emission levels are associated with the lower fabric loadings.

2.8.2.5 Estimation of Overall Dust Penetration--

It has been demonstrated that outlet dust concentrations from fabric filters depend upon several factors (48). In a general functional relationship, the dust penetration, Pn, or outlet concentration, C_o, may be expressed as:

$$Pn \text{ or } C_o \propto (\phi, C_i, W, V, C_R), \qquad (2\text{-}39)$$

where ϕ is a parameter related to the dust/fabric combination of interest, C_i is the inlet concentration, W the fabric dust loading, V the filtration velocity, and C_R a characteristic minimum emission level for the dust/fabric combination of concern. The latter C_R values have been cited as 0.5 mg/m^3 and 0.05 mg/m^3, respectively, for fly ash filtration on woven glass and cotton fabric (46,48,49).

Although, ϕ, C_i, and C_R may be treated as constants for most filter applications, both W and V will change constantly with multicompartmented, sequentially cleaned systems. Hence, the prediction of emission levels, as with pressure loss requires a computer program to solve the complex equations involved. The average filter system penetration at some time, t, for a system consisting of I compartments and J areal subdivisions per bag is also determined by successive iterations in accordance with the general summation (48):

$$Pn_t = \frac{1}{V_t IJ} \sum_{i=1}^{I} \sum_{j=1}^{J} Pn_{ij_t} V_{ij_t} \qquad (2\text{-}40)$$

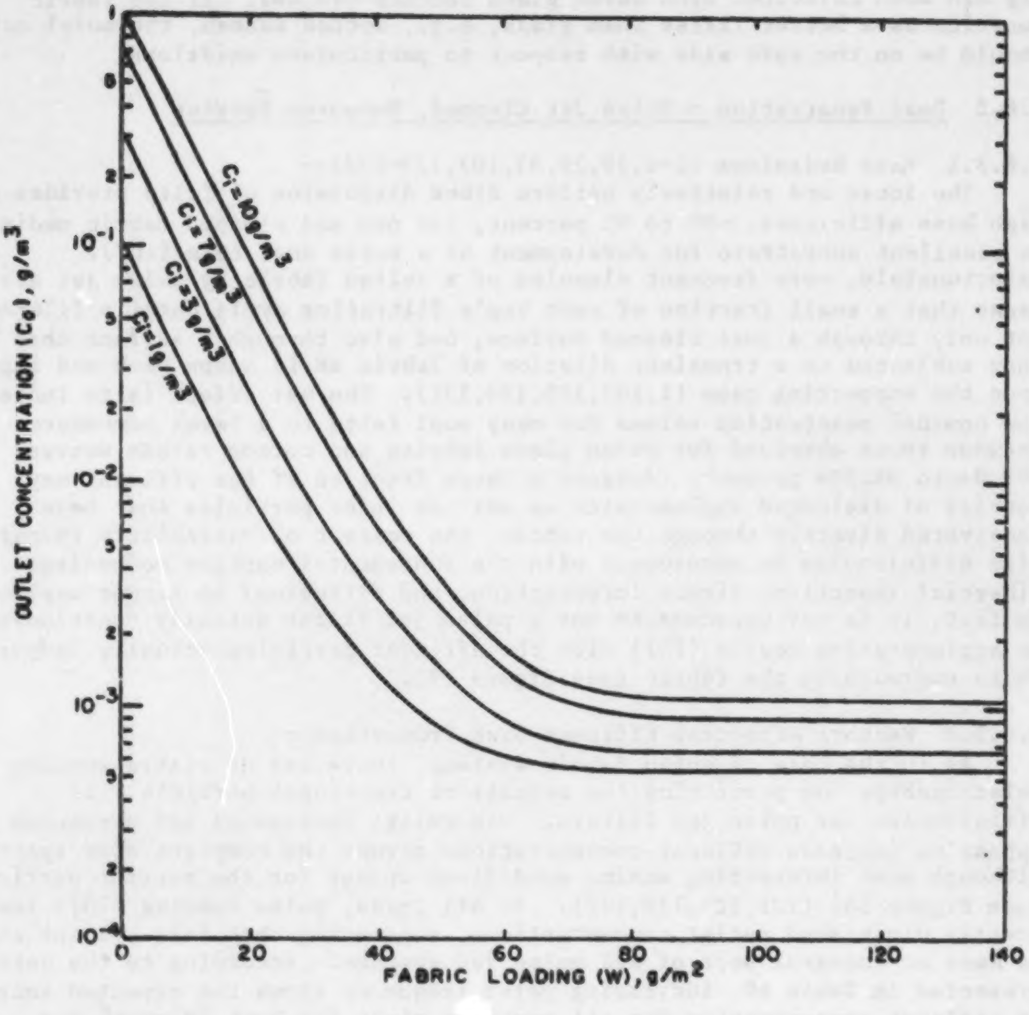


Figure 28. **Effect of inlet concentration on predicted outlet concentrations at a face velocity of 0.61 m/min with coal fly ash and glass fabrics (bench scale tests).**

The modeling procedure described in References 46, 48, 49, 100 and discussed in Appendix F, which quantitates the basic relationships shown in Equations (2-37) and (2-38), will permit reasonable estimates of filter system performance for dusts whose general properties are similar to those of coal fly ash when collected upon woven glass fabrics (46,48). If the fabric constitutes a better filter than glass, e.g., cotton sateen, the model output should be on the safe side with respect to particulate emissions.

2.8.3 Dust Penetration - Pulse Jet Cleaned, Nonwoven Fabrics

2.8.3.1 Mass Emissions (1-6,28,29,33,107,129-132)--

The loose and relatively uniform fiber dispersion of felts provides a high base efficiency, ~90 to 95 percent, for new and cleaned fabric media and an excellent subtstrate for development of a solid dust cake (107). Unfortunately, very frequent cleaning of a felted fabric by pulse jet air means that a small fraction of each bag's filtration cycle entails filtration not only through a just cleaned surface, but also through a surface that has been subjected to a transient dilation of fabric as it snaps back and impacts upon the supporting cage (1,107,125,128,131). The net effect is to increase the nominal penetration values for many wool felts to a level somewhere between those observed for woven glass fabrics and cotton sateen weaves, ~99.9+ to 99.99+ percent. Because a large fraction of the effluent may consist of dislodged agglomerates as well as inlet particles that have penetrated directly through the fabric, the concept of variability in particle size efficiencies in accordance with the fundamental capture mechanisms (inertial impaction, direct interception, and diffusion) no longer applies. In fact, it is not uncommon to see a pulse jet filter actually functioning as an agglomerating device (167) with the effluent particles actually larger than those approaching the fabric (see Figure 29).

2.8.3.2 Factors Affecting Effluent Size Properties--

As in the case of woven fabric systems, there are no viable working relationships for predicting the overall or fractional particle size efficiencies for pulse jet filters. Generally, increasing jet pressures appear to increase effluent concentrations across the complete size spectrum, although some interesting maxima conditions appear for the coarser particles, (see Figure 30) (121,125,130,132). In all cases, pulse damping (107) leads to greatly diminished outlet concentrations, suggesting that this concept should be made an integral part of all pulse jet systems. According to the data presented in Table 10, increasing pulse frequency shows the expected increase in effluent concentration for all particle sizes for both "direct" and "damped" pulses (107,132). The complex nature of the variability in effluent quality exhibited by these measurements suggests that the accurate estimation of effluent characteristics for pulse jet filters is beyond present predictive capabilities.

2.8.4 Field Performance

The literature describing the field vehavior of fabric filter systems is extensive such that only a small sampling can be presented here. Typical baghouse performance for a wide variety of operating conditions and including those situations where high temperatures, corrosion factors, and usually fine

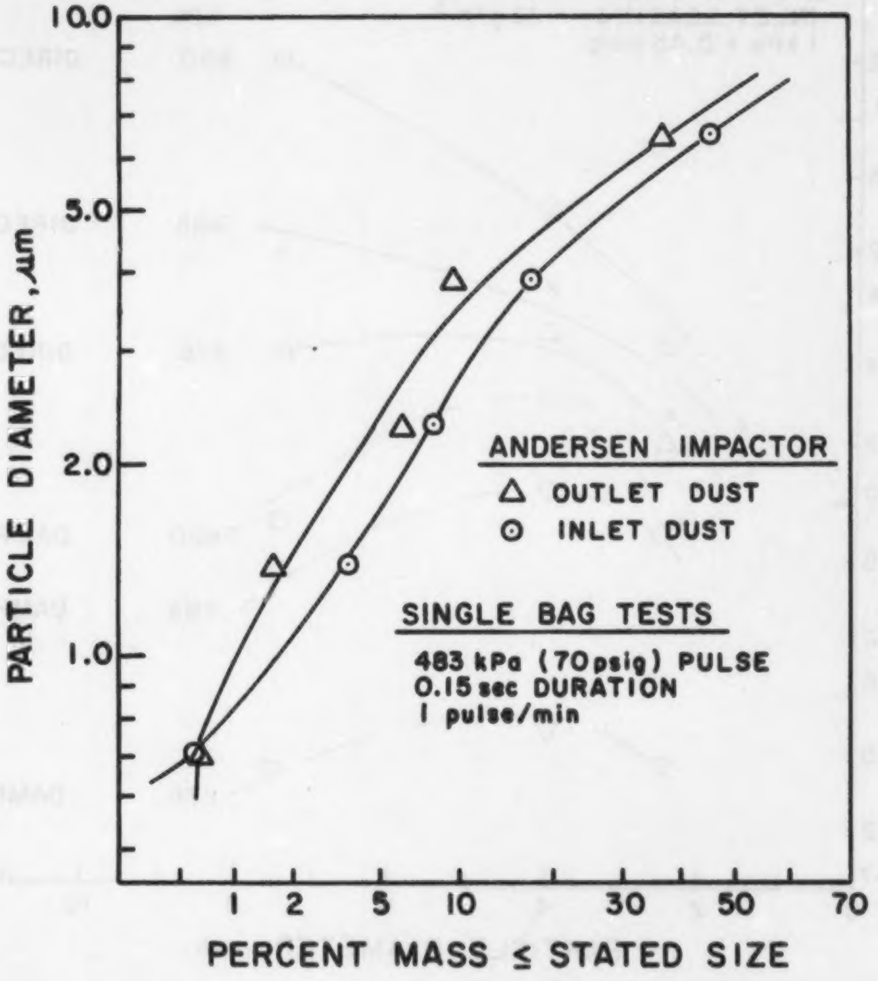


Figure 29. Coal fly ash filtration, dacron felt with pulse jet cleaning, 99.83% overall mass efficiency.

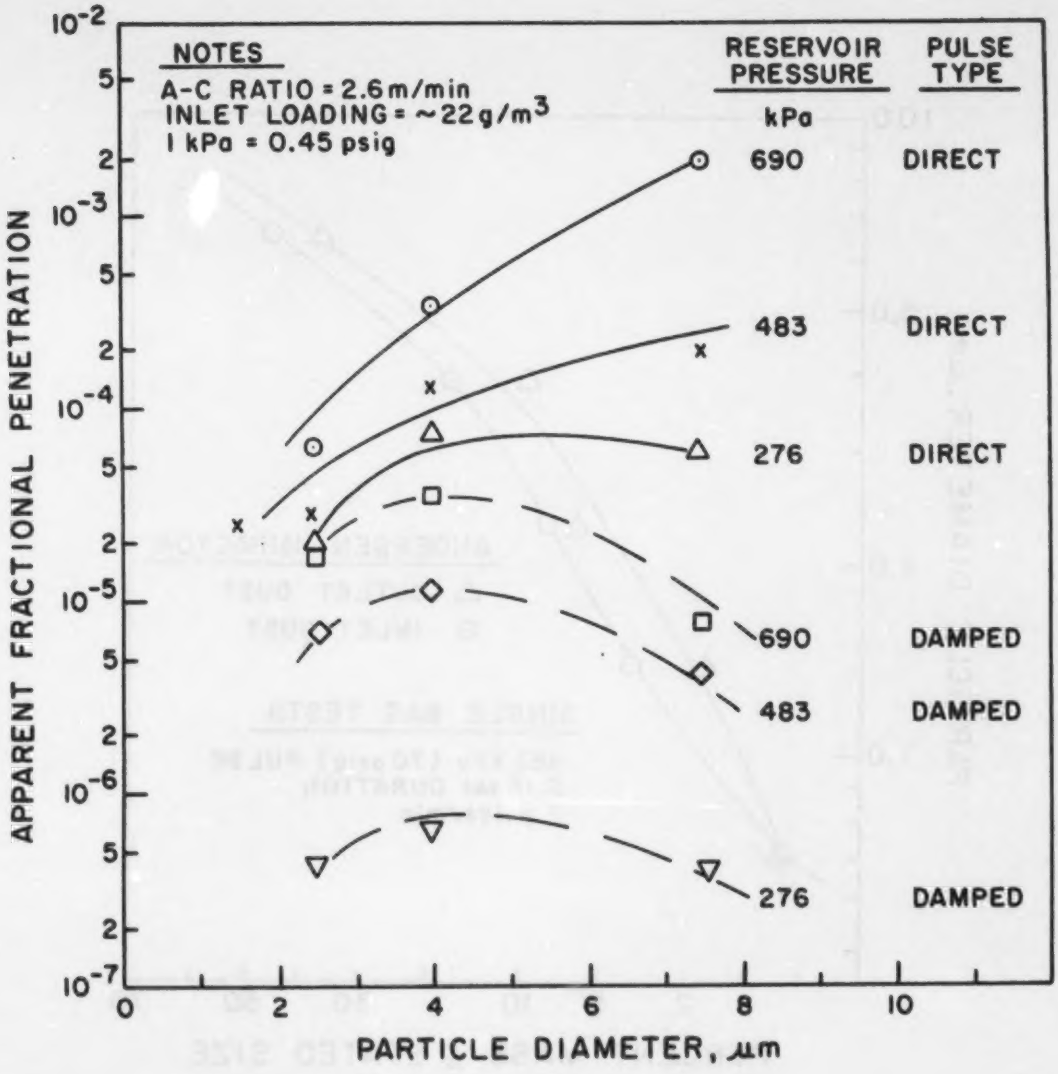


Figure 30. Apparent fractional penetration for coal fly ash versus pulse pressure and type, dacron needled bag (1.22 m x 11.4 cm).

TABLE 10. EFFECT OF PULSE DURATION AND FREQUENCY, AND DIRECT AND DAMPED PULSES ON FLY ASH FRACTIONAL PENETRATION, DACRON NEEDLED FELT AT 2.6 m/min AIR-CLOTH RATIO (107,150)

Particle diameter µm	Pulse duration* sec	Fraction penetration pulse frequency†		Penetration ratio
		2.5 pulse/min (ppm)	1.0 pulse/min (ppm)	2.5 ppm/1.0 ppm
		DIRECT PULSES		
2 - 3	0.15	6×10^{-5}	1.5×10^{-5}	4.0
	0.06	4×10^{-5}	2.0×10^{-5}	2.0
3 - 5	0.15	2×10^{-4}	1.3×10^{-4}	1.5
	0.06	1.3×10^{-4}	0.8×10^{-4}	1.6
5 - 10	0.15	4.6×10^{-4}	1.6×10^{-4}	2.9
	0.06	9.0×10^{-4}	5.0×10^{-4}	1.8
		DAMPED PULSES		
2 - 3	0.15	2×10^{-5}	1.05×10^{-5}	1.9
	0.06	0.5×10^{-5}	0.3×10^{-5}	1.6
3 - 5	0.15	2.7×10^{-5}	0.95×10^{-5}	2.8
	0.06	0.7×10^{-5}	0.6×10^{-5}	1.2
5 - 10	0.15	8.3×10^{-6}	2.5×10^{-6}	3.3
	0.06	8.3×10^{-6}	5.0×10^{-6}	1.7

*Reservoir pressure = 483 kPa (70 psig).

†Inlet fly ash concentration ∿20-25 g/m^3 (∿10 grains/ft^3).

or "sticky" dust can present difficulties is discussed in References (1,3,4,7,139-141). More specialized and often challenging applications encountered in the electric utilities area (both coal- and oil-fired boilers) are described in the following References (1,3,4,142-149). Uses in metallurgical processes, asbestos manufacture, and the asphalt concrete industry are discussed in References (154-157). Technical data treating the controversial area of fractional particle size efficiencies for fabric filters are discussed in References 150-153.

CHAPTER 3

TYPICAL BAGHOUSE PROBLEMS/CORRECTIVE ACTIONS

3.1 INTRODUCTION (1,3,7,93,94,95,137,138,161-166)

This section of the manual discusses typical problems reported for baghouse installations. A general description of potentially troublesome areas is followed by a listing of specific problems reported by fabric filter users. Finally, troubleshooting guidelines recommended by several manufacturers are presented (167-172).

Many of the problems encountered by fabric filter users arise from ancillary equipment malfunctions that have nothing to do with the collection device itself (1,7,94,162,163). Problems with fans, blowers, gas transport and distribution systems, dust handling and removal systems, and monitors and alarms are typical examples. Operational problems related to the baghouse per se most often relate to the bags themselves or the bag cleaning system (1,7,163,164). Other problems may occur as a result of transient or process upset conditions affecting dust concentration and its physical properties or gas stream temperature, humidity, and chemical composition. Figure 31 shows schematically the principal baghouse components and ancillary equipment used for the filtration of coal fly ash (170).

3.2 ANCILLARY EQUIPMENT

3.2.1 Fans and Blowers

Fans and blowers handling dust-laden exhaust gas or cleaned effluent can present a variety of problems (94,95,161,166). The proper choice of construction materials, fans, and motors in conjunction with careful installation will minimize motor overloading, bearing wear, and motor damage. Typical problem areas include excessive fan vibration, worn bearings, and malfunctioning belts, drives, gears, and electrical controls.

The gas transport and distribution system, consisting of exhaust ventilation hoods and all connecting ductwork between the dust sources and the baghouse, requires careful design to ensure satisfactory operation. Improper selection of construction materials can result in duct abrasion or chemical attack. Incorrect duct sizing leads to unwanted settlement if the diameters are too large or excessive abrasion and pressure loss if the ducting is undersized (1,7,165,166). The actual shape and degree of enclosure of exhaust hooding have an important bearing on baghouse operation with respect to dust entrainment and volume of gas arriving at the baghouse. Furthermore, if the baghouse is unable to accommodate the inlet dust loadings, its gas handling capacity may not satisfy the exhaust requirements at the various exhaust points. Other system components that can malfunction are compartment isolation valves and emergency bypass dampers. In the former case, partial valve closure leads to inadequate cleaning, while a faulty emergency bypass damper can cause irreversible damage to the filter medium (95,161-165).

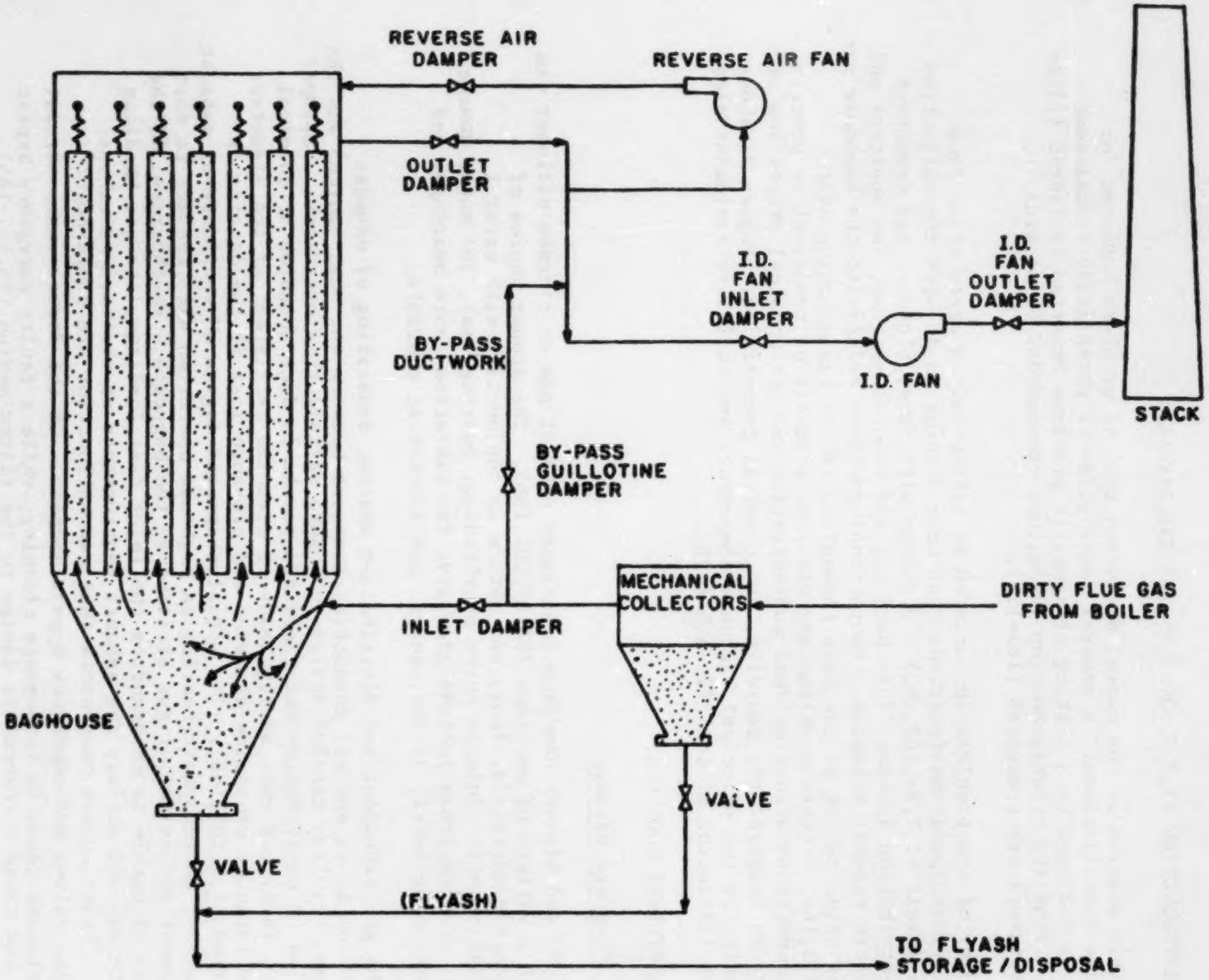

REVERSE AIR DAMPER
REVERSE AIR FAN
OUTLET DAMPER
I.D. FAN INLET DAMPER
I.D. FAN OUTLET DAMPER
STACK
I.D. FAN
BY-PASS DUCTWORK
BY-PASS GUILLOTINE DAMPER
MECHANICAL COLLECTORS
DIRTY FLUE GAS FROM BOILER
INLET DAMPER
BAGHOUSE
VALVE
VALVE
(FLYASH)
TO FLYASH STORAGE / DISPOSAL

Figure 31. Typical boiler/baghouse schematic diagram (courtesy of Zurn Industries, Inc., Air Systems Div.).

3.2.2 Dust Handling Systems

Dust handling and removal systems consisting of hoppers, rotary valves, airlocks, and screw conveyors or pneumatic conveying systems, must be properly designed to avoid deterioration, leaking, jamming, plugging, or dust bridging. Hoppers must be of sufficient capacity and slope to avoid the aforementioned overflow and bridging problems. Hopper heaters, vibrators, or level indicators may be required in many applications. Provision of some extra-heavy hopper panels also allows for a primitive but often effective dust disledging process with a sledge hammer during emergencies (1,3).

3.2.3 Monitoring Equipment (1,7,47,163,165)

Additional auxiliary equipment necessary for proper overall system operation are monitoring and alarm devices for displaying and/or recording system and compartment gas flows and pressure losses, compartment isolation events, baghouse inlet and outlet temperatures, cleaning system operation and sequencing, particulate emissions, and bag failures (extreme plugging or rupture).

3.3 BAGHOUSE COMPONENTS (93-95,163-166)

3.3.1 Fabric (1,4,8,94,96,97,99,101-106)

The heart of the baghouse is the bag or fabric material that usually represents the highest maintenance component in any filter system. Problems with bags that can lead to excessive emissions or inadequate service life include: pinhole leaks; gross tears, punctures or burn holes; thermal, chemical, or moisture damage; inadequate tension (123); twisting, chafing, or abrasion; and ineffective cleaning and/or blinding (irreversible plugging of fabric structure) that can cause excessive pressure losses(93-95,161-166). Problems associated with bag proximity and accessibility (reach), support structures (wire mesh cages or anticollapse rings), and bottom and top suspension and tensioning systems must be avoided to guarantee maximum on-line performance.

3.3.2 Cleaning System (1,46,48,49,95,107,125-132)

Equally as important as the fabric selection is the fabric cleaning method. Mechanical shaking devices can experience mechanical failures because of underdesign, limited capacity for bag tension adjustment, or poor mechanical linkages (1,107). Pulse jet cleaning systems can be rendered ineffectual due to inadequate compressed air pressure and/or volume, water or dust in compressed air lines, or lack of flexibility in adjusting pulse frequency duration, and sequence to the cleaning demands (128,132). Reverse air cleaning systems can develop problems because of insufficient reverse flow velocity and duration, total bag collapse if not prevented by anticollapse rings or compensatory bag tensioning, or bag damage caused by overtensioning or supplementary shaking (107,123). Reverse jet (RJ) (traveling blowring) cleaning can present problems similar to those posed by pulse jet (PJ) and reverse air (RA) systems as well as unique difficulties relating to plugged blowring nozzles, dust caking on the rings, or severe bag abrasion by inadequate blowring clearance. The present consensus is that pulse jet collectors have replaced the formerly popular reverse jet device because of fewer maintenance difficulties.

3.3.3 Basic Structure (1,4,7,94,164-166)

Other baghouse problems, aside from those with bags or cleaning equipment, relate to the environmental responses of the materials of construction (rusting, chemical attack, moisture, defective welds, stress failures,) inoperable access doors and inspection ports, insufficient and/or the wrong choice of gasketing or insulation, lack of supplementary heating, and excessive temperatures in compartments isolated for maintenance.

3.4 PROCESS CONDITIONS

Depending on the type and nature of a specific process (steady state, batch or cycling), any one of several situations may develop that can result in a temporarily or permanently impaired emission control system (1,4,7,95). Variable process conditions may generate unusually high dust concentrations or very fine particles, dust of an atypical character (hygroscopic, sticky, or with abnormal electrostatic charge), or rapidly changing gas flows and temperatures (60,61). Any of the above conditions may cause operating difficulties due to dust adherence to fabric, ducts, hoppers, and dampers. These transient or upset process conditions are of special concern for those systems handling explosive, flammable, and/or toxic substances such as grain dust or asbestos or for processes involving high temperature operations, such as boilers, furnaces, or rotary kilns (55-57). Since a one-time occurrence of an excessively high temperature may destroy the fabric material or result in a baghouse fire, bypass systems or emergency water deluge systems are normally provided (62).

3.5 FABRIC FILTER USER INPUT

Current user problems with fabric filter systems based upon comments from 19 plants and embracing 30 individual filter systems are summarized in Table 11 (112). Since 17 of the operations were related to fly ash filtration from power boilers, the observations do not necessarily reflect typical industrial filter performance. On the other hand, they do provide a general indication as to what has been experienced with baghouses using four cleaning methods; i.e., 18 reverse air, 2 reverse jet, 8 pulse jet, 2 reverse air with shake-assist and supplied by 10 different manufacturers (61). They also represent operations where high temperature (50-53) and moisture (61) factors require special consideration. The frequency of any given problem does not indicate the severity of the incident. A notable feature of these findings is that most users reported minimal problems with their equipment and, in general, were pleased with overall system performance. Based upon informal reportings from other sources, however, the data presented in Table 11 appear to paint an overly optimistic picture of fabric filter experience in heating or utility boiler applications.

TABLE 11. TYPICAL USER PROBLEMS ENCOUNTERED WITH FABRIC FILTER SYSTEMS AND FREQUENCY OF OCCURRENCE (112)

Typical problems	Problems[a]		
	Estimated frequency		
	Rarely	Yearly	Monthly
A. FANS AND BLOWERS			
1. Fan underdesigned or underpowered	X		
2. Vibration and balance	X	X	
3. Bearing wear	X	X	
4. Fan speed adjustment - belting, gears, electric controls	X		
5. Dust erosion, impeller and scroll	X		
6. Materials of construction - wrong choice or underdesigned	X		
7. Electric motors - inadequate cooling, overloading	X		
B. GAS-AIR TRANSPORT AND DISTRIBUTION			
1. Poor hood design, excessive solids entrainment (high dust loading)	X		
2. Incorrect duct sizing - duct abrasion or dust settlement	X		
3. Materials of construction - underdesign, poor resistance to heat and chemical attack	X		
4. Absence or incorrect use of baffles and guide vanes	X		
5. Poor flow distribution in parallel flow paths and among adjoining bag compartments	X		
6. Isolation valves and dampers - leakage, jamming, slow response, underdesign		X	
C. BAGS AND FABRICS			
1. Excessive dust penetration	X	X	
2. Excessive pressure loss	X	X	

(continued)

TABLE 11 (continued)

Typical problems	Problems[a]		
	Estimated frequency		
	Rarely	Yearly	Monthly
3. Inadequate service life	X		
4. Ineffective fabric cleaning	X		X
5. Incorrect cleaning method	X		
6. Design fabric cleaning method	X		
7. Pinhole leaks	X		X
8. Gross fabric tears, punctures, burn holes	X	X	
9. Thermal, chemical, or moisture damage		X	
10. Bag tension adjustments	X	X	
11. Bag thimbles and floorplates	X	X	
12. Bag accessibility (reach) for repair and replacement	X		
13. Bag proximity, twisting, chafing, and abrasion	X		
14. Spare parts availability	X		
D. DUSTS AND FUMES			
1. High concentrations	X		
2. Fine particle size	X		
3. Stickiness - electrostatic charge or hygroscopicity	X		
4. Adherence to fabric, ducts, hoppers, dampers	X	X	
5. High temperature - hot embers	X		
6. Explosive, flammable, and/or toxic	X		

(continued)

TABLE 11 (continue)

Typical problems	Problems[a] Estimated frequency Rarely	Yearly	Monthly
E. FABRIC CLEANING			
1. Mechanical shaking - mechanical failures and underdesign			
2. Mechanical shaking - no adjustment capability, insufficient energy			
3. Pulse jet cleaning - inadequate air pressure and volume	X		
4. Pulse jet cleaning - water in compressed air			
5. Pulse jet cleaning - lack of flexibility in regulating pulse frequency, duration, and sequence			
6. Reverse flow cleaning with bag collapse - inadequate reverse flow treatment (velocity and duration)	X		
7. Reverse flow cleaning - total bag collapse not prevented by anticollapse rings or bag tension	X		
8. Reverse flow cleaning - bag damage by overtensioning or shaking	X		
9. Improper or defective coupling of pressure sensors or timing devices used to initiate cleaning	X		
10. Confusing and poorly located control panels	X		
F. BAG COMPARTMENT(S) AND SUPPORTING STRUCTURE			
1. Materials selection - underdesign and instability	X		
2. Rusting, chemical attack, moisture	X	X	
3. Defective welds and gasketing	X		
4. Inoperable access doors and inspection ports	X		
5. Faulty insulation	X		
6. Lack of supplementary heating	X		
7. Excessive temperature in compartments ioslated for cleaning	X		

(continued)

TABLE 11 (continued)

Typical problems	Problems[a] Estimated frequency Rarely	Yearly	Monthly
G. DUST COLLECTION AND REMOVAL			
1. Undersized hopper(s)	X		
2. Poor hopper design - slope	X		
3. Dust bridging - angle of recline or stickiness	X	X	
4. Hopper heating - dewpoint and moisture effects	X		
5. Hopper overloading - no level sensors	X		
6. Airlocks and rotary valves - leaks and jamming	X	X	X
7. Screw flite conveyors - underdesign and/or underpowered, jamming	X		
8. Pneumatic transport - plugging, moisture	X		
H. FILTER SYSTEM MONITORING AND ALARM DEVICES			
1. System gas flow	X		
2. Compartment gas flow	X		
3. System pressure loss	X		
4. Compartment pressure loss	X		
5. Baghouse temperature	X		
6. Hopper dust level	X		
7. Particulate emissions - extractive batch sampling	X		
8. Particulate emissions - continuous monitoring	X	X	
9. Opacity monitors	X	X	

[a] "X" designates one or more plant for indicated frequency category, blank spaces indicate no reportings.

In Table 11, problems are grouped in selected categories such as fans and blowers, gas-air transport and distribution, bags and fabrics, etc. The class most often checked, other than "rarely", was bags and fabrics (Category C) for which a total of 56 problems were indicated. With respect to the other problem categories, difficulties associated with isolation valves and dampers (B.6.) were followed by opacity monitors (H.9.), airlocks and rotary valves (G.6.), fabric pinhole leaks (C.7.), and fan vibration and balance (A.2.).

Structural underdesign was one reason for valve or damper malfunction although corrosion and/or dusting of bearing surfaces and incomplete damper closure due to thermal warping were contributing factors.

Opacity monitors often failed because of dust deposition on the light sources and/or receptors. Inadequate thermal shielding and shock mounting of electronic components also created problems as did the improper location of the sensors with respect to representative measurements. A combination of mechanical underdesign coupled with inadequate motor powering for the dust of interest (size, hardness, degree of compaction) contributed to airlock and rotary valve problems. Moisture plus chemical reactions also caused formation of a very difficult-to-transport hopper material. Dust deposition on fan blades, due to moisture and/or lack of a substantial pad for fan and motor mounting, created an imbalance followed by destructive vibrations.

Although the sampling was extremely limited relative to the actual number of baghouse installations in current use, some general comments can be made regarding specific collector types (112):

- Reverse air with bag collapse--problems with isolation valves and reverse air duct corrosion were most often cited by users of this equipment. The main cause for reverse air duct corrosion was the flue gas trapped inside between cleaning intervals that subsequently cooled to below its dewpoint temperature. One user recommended that the system bypass dampers be installed so that flue gas passed through the inlet and outlet plenums. By using this design, the baghouse will heat up faster when brought online. Ambient air should not be used directly for reverse air cleaning in any application that might reduce baghouse temperatures to below dewpoint levels.

- Reverse air with bag collapse plus shake assist--Based upon the experience of two facilities included in Table 11 as well as outside information sources, the most common problem with the above cleaning approach is insufficient dust removal that leads to excessive operating pressure losses. The actual difficulty appears to be the result of dust caking when near dew point operations occur. Under these circumstances, the fly ash adheres very strongly to the fabric.

- Pulse-jet Collectors--Shortened bag life and malfunctioning compressed air delivery systems are other problem areas indicated in Table 11. Abrasion and tearing of the felted fabric due to repeated impact on the jagged edges of improperly constructed cages was a major cause of bag damage. Failure to dewater the compressed air supply also increased dust adhesion and inadequate pulse pressure (and delivered pulse volume) led to diminished bag flexure.

- Reverse-jet Collectors--The major design and operating problems encountered with reverse jet collectors relate to the spacing between the blowring and the bag. With excessive clearances between blowring and bag, the air jet velocities are not high enough to dislodge the dust cake. Conversely, too close spacing between the ring and the bag causes fabric damage and reduced service life.

According to the Table 11 information sources, power plant operations were not seriously impaired (< 5 percent) by the indicated problems. This statistic should not be extended to industry as a whole, however, because of generally better maintenance within the utilities industry and the fact that experience with fabric filters for fly ash removal involves a relatively brief period in comparison to many industrial applications.

3.6 PROBLEM RECTIFICATION (167-172)

Information was obtained from several baghouse manufacturers and other sources to establish current practice for solving common baghouse problems. Table 12 provides a comprehensive listing of troubleshooting guidelines based upon several manufacturers' bulletins and other relevant documents (167-172). Where the problems, symptoms, and/or remedies are specific to a given collector type, they are so designated. It should be recognized that many of the problems, causes, and solutions may be so interrelated that correcting one problem (e.g., defective cleaning system) may automatically correct another (e.g., excessive pressure loss).

TABLE 12. TROUBLESHOOTING GUIDELINES FOR COMMON BAGHOUSE OPERATING PROBLEMS[a]

Problem or symptom	Probable cause	Remedy
1. Visible discharge/dust in clean air plenum	a. Bags improperly installed	• Check bag installation procedures; repair as necessary.
	b. Bag clamps too loose	• Tighten bag clamps.
	c. Torn or damaged bags	• Replace or tie off and replace at later date.
	d. Leakage at tube sheet (field assembled units)	• Check tube sheet joints; repair as necessary.
	e. Venturi fasteners loose or missing (PJ)	• Repair as necessary
	f. Insufficient filter cake	• Allow more dust to build up on bags by cleaning less frequently. Use a precoat (startup only).
	g. Bags too porous	• Send bag out for permeability test and consult with manufacturer.
	h. Inadequate bag tension	• Check tension and/or springs for compression to proper length.
2. Excessive pressure drop (a differential pressure of 1 to 6 in. W.C. can be considered normal)	a. Gas flow too high	• Check fan speed and damper positions; adjust to specified ratings. Check system design. Check isolation dampers, valves, linkage and seals. Check air supply on pneumatic operators.
	b. Improper bag cleaning action	• Refer to Problem 6.
	c. Improper dust discharge from hopper.	• Check seal around slide gate (or in airlock); reseal if leakage is occurring. Ensure continuous dust removal from hoppers.
	d. Moisture blinding of filter bafs	• Correct cause of excess moisture and replace bags. Recovery of bag is sometimes possible by running cleaning system (without moving air through collector) from 1 to 30 hours.

(continued)

TABLE 12 (continued)

Problem or symptom	Probable cause	Remedy
	e. Clogging of filter bags	• Eliminate oil or static charges from collector. Control airflow during startup. Check for excessive operating temperature. Check to see that dust characteristics have not changed. If using laundered bags, check for shrinkage.
	f. Static electricity in collector	• Increase relative humidity if possible. Use grounded filter bags.
	g. Excessive dust in clean air plenum (can diminish cleaning effectiveness by plugging the bags in the reverse direction). Damaged or inefficient bags.	• Clean plenum, check bags for dirt on clean side; clean or replace bags.
	h. Insufficient blowring air (RJ)	• Check drive belts on blower, blower speed, blower rotation; replace blower inlet filter; check blowring hose; check blowring for clogged slots.
	i. Nonoperative blowring drive (RJ)	• Check belts on reversing motor; check for broken chain or chain off sprocket; check sheaves or sprockets for loose set screws, check setting of tripper pins; check tripper lever for bend, looseness, or binding.
	j. Incorrect pressure reading	• Clean out pressure taps; check hoses for leaks; check for proper fluid in manometer; check diaphragm in gauge.
3. High bag failure rate		
a. Deterioration/decomposition	a. Improper bag material for dust chemical composition	• Analyze dust and check with manufacturer. Treat with neutralizer prior to collector.
	b. Operating below acid dewpoint	• Increase gas temperature. Bypass collector during start-up/shutdown.
b. Wearing out/abrasion	a. Baffle plate worn out	• Replace baffle plate.
	b. Excessive dust loading and/or large abrasive metallic particles	• Install primary collector upstream of baghouse.

(continued)

TABLE 12 (continued)

Problem or symptom	Probable cause	Remedy
	c. Cleaning cycle too frequent (PJ) (PP)	• Increase cleaning interval.
	d. Shaking too violent (S)	• Decrease shaking frequency and/or amplitude.
	e. Inlet air not properly baffled from bags	• Consult manufacturer.
	f. Pulse pressure too high (PJ) (PP)	• Reduce pressure.
	g. Bag cages have barbs (PJ) (PP)	• Remove or smooth barbs.
c. Burning or accelerated fabric deterioration	a. Stratification of hot and cold gases	• Install baffles to create turbulence.
	b. Sparks entering collector	• Install spark arrestor.
	c. Failure of cooling or dilution system	• Check design with manufacturer.
	d. Excessive temperature	• Reduce operating temperature or use filter bags of higher temperature rating.
d. Other	a. Hopper bridging	• Material buildup into the bag area can overstress filter elements. Locate cause of bridging and correct; clean out hopper.
4. Filtering action impaired	a. Improper cleaning system operation	• Refer to Item 6.
	b. Excessive moisture entering collector blinding bags	• Refer to Item 2.d.
	c. Incorrect gas flow	• Refer to Item 5.
	d. Incorrect bag material for gas composition	• Replace with bags of proper material for type of dust.
	e. Gas temperature higher than specified	• Refer to Item 3.c.d.
	f. Static electricity buildup in collector	• Refer to Item 2.f.

(continued)

TABLE 12 (continued)

Problem or symptom	Probable cause	Remedy
5. Gas flow through system below design rating/low fan amperage	a. Incorrect fan speed (or direction)	• Check rotation, correct if wrong, change sheave ratio.
	b. High differential pressure drop	• Refer to Item 2.
	c. Fan belts slipping	• Check tension on fan belts and adjust if necessary.
	d. Air leakage in gas system	• Check access doors, plenum, manifolds, duct work; repair leaks.
	e. Leakage in dust collection system	• Check for hopper or discharge system leakage; repair as necessary.
	f. Blocked gas system	• Check bags for blinding, obstruction in duct passages, or closed damper; clean or repair as necessary.
	g. Fan and motor sheaves reversed	• Check drawings and reverse sheaves.
	h. System static pressure too high	• Measure static pressure on both sides of fan and discuss with designer of duct velocity and configuration.
	i. Excessive moisture	• Refer to Item 2.d.
	j. Infrequent cleaning	• Refer to Item 6.
6. Improper cleaning system operation		
a. Blowring reversing switch failure (RJ)	a. Worn cams or rollers	• Repair or replace switch assembly.
	b. Improperly set tripper level	• Adjust arc of movement for approximately 60° above or below horizontal; uneven arc will cause switch to work in only one direction.
	c. Dirt in switch	• Check to see that enclosure is properly installed.

(continued)

TABLE 12 (continued)

Problem or symptom	Probable cause	Remedy
b. Inability to maintain compressed air pressure (PJ), (PP)	a. Faulty or undersized compressor	• Check compressor manual. Pressure should normally be maintained between 80 to 110 psig.
	b. Leakage or restriction in main air line	• Locate and repair leak or restriction.
	c. Defective timer operation	• Make sure all valves are being activated. Check for sticking timer relay or pulse longer than 0.15 seconds. Replace timer if necessary.
	d. Improper operation of solenoid or diaphragm valves	• Examine valves for dirt or short circuit in wiring which can cause valves to stick open. Clean and check pilot plunger.
	NOTE: Steady rush of air indicates open valve; no air pulse indicates plugged valve. Solenoid valves require a minimum of 5 psig to close. A long compressed air run after the shutoff valve has closed can prevent the required 5 psig from developing. The solution would be provision of reservoir and shutoff valve near the collector.	
	e. Compressed air consumption too high	• Reduce cleaning cycle, duration of pulse, or supply pressure, if possible.
	f. Plugged dryer	• Replace desiccant or bypass dryer if permitted.
	g. Supply line too small	• Consult design.
	h. Compressor worn	• Replace rings.
c. Reduced compressed air consumption (PJ), (PP)	a. Pulsing (solenoid) valves not working	• Check diaphragm, springs, and pilot valves.
	b. Failed timer	• Check terminal outputs.
d. Inadequate cleaning (S)	a. Defective shaker mechanism	• Check shaker speed, amplitude, and bag tension; adjust if required. Check for broken linkage and lost pins connecting linkage.

(continued)

TABLE 12 (continued)

Problem or symptom	Probable cause	Remedy
7. Moisture in baghouse	a. Insufficient preheating	• Run system with hot air prior to starting process gas flow.
	b. System not purged after shutdown	• Keep fan running for 5 to 10 minutes after process is shut down.
	c. Wall temperature below dewpoint	• Raise gas temperature, insulate unit, install auxiliary heaters. Lower dewpoint by keeping moisture out of system.
	d. Cold spots through insulation	• Eliminate direct metal lines through insulation.
	e. Compressed air introducing water (RJ, PP)	• Check automatic drains, install aftercooler, install dryer.
	f. Repressuring air causing condensation (RA, PP)	• Preheat repressuring air; use process gas as source of repressuring air.
	g. Moisture in compressed air line	• Make sure cooler or water trap is functioning.
8. Insufficient dust pickup at emission points	a. Leaks in ductwork, access doors, and/or hopper discharge valves	• Repair leaks so that air does not bypass source.
	b. High differential pressure	• Refer to Item 2.
	c. Slipping fan belts or fan rotating in wrong direction	• Check fan and repair as necessary.
	d. Clogged duct or closed or partially closed gate or damper	• Check all ductwork and damper positions and operation.
	e. Duct size or run other than original design/inadequate system design	• Check design specifications with manufacturer. Close open areas around dust source. Check for cross drafts that overcome suction.
9. Fan problems—excessive wear, noise, vibration, or motor overloading	a. Improper fan	• Check with fan manufacturer to see if fan is of proper design for application.
	b. Fan speed too high	• Consult fan manufacturer.

(continued)

TABLE 12 (continued)

Problem of symptom	Probable cause	Remedy
	c. Dust building up on fan blades.	• Clean fan and check for water.
	d. Improper fan wheel	• Check with manufacturer.
	e. Sheaves not balanced	• Have sheaves dynamically balanced.
	f. Worn bearings	• Replace bearings.
	g. Air volume too high	• Refer to Item 2.a.
	h. Motor not sized for cold start	• Dampen fan at start-up, reduce fan speed, provide heat faster, or replace motor.
10. Hopper/Dust Discharge System Failure or excessive wear		
a. High screw conveyor or airlock wear	a. Screw conveyor or airlock undersized	• Measure hourly collection of dust and consult manufacturer.
	b. Conveyor or airlock speed too high	• Check and reduce speed.
	c. Thermal expansion	• Consult manufacturer.
b. Frequent screw conveyor or airlock failure	a. Undersized equipment	• Consult manufacturer.
	b. Misaligned screw conveyor	• Check and align.
	c. Overloading components	• Check sizing and design of all components versus dust delivery rates.
c. High pneumatic conveyor wear	a. Blower set too fast	• Check and reduce speed.
	b. Undersized piping	• Review design--slow down blower or increase pipe size.
d. Pneumatic conveyor pipes plugging	a. Elbows designed with too short a radius	• Replace with long radius elbows.
	b. Overloading pneumatic conveyor	• Review design.
	c. Slug loading of dust	• Feed dust gradually.

(continued)

TABLE 12 (continued)

Problem or symptom	Probable cause	Remedy
	d. Moisture in dust	• Refer to Item 7.
e. Material bridging in hopper	a. Moisture in baghouse	• Refer to Item 7.
	b. Dust being stored in hopper	• Ensure that dust is removed continuously.
	c. Insufficient hopper slope	• Rework or replace hoppers.
	d. Conveyor opening too small	• Use a wide flared trough.
f. Excessive corrosion of baghouse structure, bag mountings, wire cages	a. Air in-leakage through defective gaskets	• Proper inspection and maintenance.
	b. Missing or damaged insulation	• Heat tracing and/or gas temperature elevation.
	c. Frequent dewpoint excursions	

[a]PJ = pulse jet
PP = plenum pulse
RA = reverse air
RJ = reverse jet
S = shaker

CHAPTER 4

BAGHOUSE INSPECTIONS, TYPES AND PROCEDURES

4.1 INTRODUCTION (1,163,164)

Inspections of fabric filter systems must be performed on a routine basis to ensure proper functioning of equipment. This is especially important in applications where highly toxic and/or hazardous materials are being collected or in situations where the cleaned effluent is recirculated to the working area for energy conservation.

Baghouse inspections fall into two main categories: (1) those conducted by plant personnel (sometimes in conjunction with the baghouse manufacturer) as part of system start-up, troubleshooting, and routine maintenance, and (2) those performed by field inspectors representing regulatory enforcement agencies for purposes of compliance determination, permit renewal, or problem assessment.

4.2 INSPECTIONS PERFORMED BY PLANT PERSONNEL

4.2.1 Background (161-165)

Those inspections performed by baghouse users and/or vendors are typically related to initial start-up and equipment shakedown, problem solving, general bag replacement, and maintenance evaluations. In subsequent paragraphs, inspection categories will be discussed in the following sequence: prestart-up, start-up, troubleshooting, and general preventive maintenance, including bag replacement and cleaning.

Although an enforcement agency inspector may only occasionally witness a start-up operation or review a user's troubleshooting or preventive maintenance program, the procedures are discussed here to acquaint inspection personnel with the routines involved in installing, debugging, and maintaining a fabric filter system. Such background material will enable air pollution control agencies to make more accurate assessments and evaluations of the operating and maintenance procedures practiced at a given facility.

It is emphasized that the guidelines provided in this manual should be used to augment and not replace the information ordinarily provided in start-up, operating, and maintenance manuals supplied by the manufacturer for the specific baghouse undergoing inspection (1,4,94,161-166). After gaining experience with his fabric filter system, the user frequently develops a set of start-up, operating, and maintenance procedures that are uniquely adapted to his needs.

4.2.2 Prestart-Up (161)

Since most fabric filter systems use a centrifugal fan as the gas mover, the compatibility of the fan and collector is extremely important. On start-up with unused fabrics, collector resistance will be considerably lower than the operating design level, perhaps 0.5 instead of 6 in. water. Consequently, the gas delivery rate (without throttling) will exceed the design value with the possibility of two undesirable effects. The fan power level may rise to the point of motor overload, and/or the higher-than-design volume flow may cause excess penetration due to seepage, as well as damage to the filter medium (164-166).

In many cases, the overall system resistance is so high so that the variations in pressure loss between new and seasoned fabrics are too small to affect significantly the fan capacity (1,7,94). For those systems where the design pressure loss across the fabric represents a large fraction of the total system pressure loss, the overload condition can be minimized by damper adjustment, selection of a fan with nonoverloading characteristics, or adjustable inlet vanes. Caution must be exercised in the start-up of high temperature systems with fans handling air at ambient temperature (161). All dampers and/or inlet vanes should be partially closed at start-up to reduce power consumption. After the correct fan speed is reached and the system temperature has approached the operating level, dampers may be opened cautiously to avoid motor overload. It should be noted that rough fan operation (vibration and noise) should be expected when dampers are partially closed. In special systems such as air classifiers that are highly sensitive to flow change, an automatic flow controller consisting of a motor-operated damper with a fan speed regulator may be helpful (161). Similar controls will also attenuate minor fluctuations when compartments go off-and online during cleaning.

Before initiation of normal service, there are several items that must be checked on any fabric filter system (161-166):

- Inspect all bag compartments and ducting to see that joints have been made tight with sealing compounds or gasketing. The general location of air leaks in either positive or negative pressure baghouses can often be detected by the air noise while exact locations can be established by applying a soap solution to suspected leak areas.

- Tighten all bolts properly and lubricate threaded elements on clamps and door latches for corrosion protection and easy access.

- Secure fabric bags properly to floor thimbles or cages and allow for required tension adjustments. If bags are furnished with ground wires to guard against sparking (and dust explosions), they should be securely connected to the tube sheet which, in turn, must be well grounded.

- Check all system controls to verify installation and operation in accordance with manufacturer's recommendations (161,167-172).

- Inspect fan to ensure that it rotates in the proper direction since accidental reversal of impeller motion reduces but does not change the direction of air flow. A visual inspection is recommended to identify this occasional cause of high pressure loss, reduced amperage, and diminished air handling capacity.

- Avoid operating conditions involving excessive temperatures, high humidities, and high dust loadings. These steps are important regardless of the collector type or the process being controlled.

- Check the fan and motor system for vibration, noise, and, in particular, overheated bearings; the latter signaled not only by high temperatures but also by acrid "hot metal" odors.

4.2.3 Baghouse Start-up--Standard Procedure (167-172)

The start-up (and shutdown) procedure for any baghouse depends upon the collector type (shaker, reverse air, pulse jet) and the process and/or emissions being controlled. As examples of real life applications, we have presented an abridged version of (a) the general procedures recommended by the manufacturer (Mikro-Pul Corp.) of a pulse jet baghouse (168) for a spray drying operation and (b) the specific procedures employed during start-up of a Zurn Industries reverse air baghouse (170) controlling fly ash emissions from two coal-fired boilers. The following guidelines are samplings of the data supplied the user by manufacturers of filtration equipment to ensure that the systems will provide the service for which they were intended.

4.2.3.1 General Start-up Procedures for a Pulse Jet Baghouse with Spray Drier or Process Equipment (168)--

Preliminary adjustments must be made in the process itself before installing bags in the collector. An incorrectly functioning dryer or other malfunctioning process equipment may result in destruction of the bags if temperature or moisture content is not under control. When using drying equipment, the collector should be preheated from 30 minutes to 1 hour before initiating filtration to avoid condensation within the baghouse and specifically on the fabric surface. The above time interval, which applies to many indirect heating systems such as steam coils or electrical elements, also depends upon the power consumption and location of heating surfaces. In the case of asphalt concrete plants where drier flue gas may be used for preheating, the desired baghouse temperature, ~300°F, may be reached in a few minutes.

- When starting up with new filter bags, proportionately higher air flow through the low resistance surface of the fabric can increase particle impingement speeds to levels where bag abrasion may take place. The above problem and that of bag blinding due to very fine or sticky materials are lessened by adjusting inlet and/or outlet damper controls to their half-flow settings.

- The inlet damper should be opened fully only after the bag pressure differential has increased to 3 to 4 in. water.

- The timer controlling the compressed air pulses should not be activated until the differential pressure has reached 4 to 5 in. water unless operating conditions demand a lower pressure drop.

- During normal start-up with seasoned or conditioned bags, apply power to all auxiliary equipment (except fan), energize timer, and turn on compressed air.

- Turn on fan motor with the system damper nearly closed to prevent motor overload during the starting power surge.

- Maintain the pressure loss across the fabric within its preset range (which may vary from 1 to 6 in. water according to the cleaning requirement) by adjustment of the pulse jet cleaning cycle. More frequent and higher pressure pulses will reduce the bag pressure loss whereas the opposite actions will increase bag pressure loss should the need arise to reduce dust penetration.

- System shutdown should be undertaken by first turning off the fan followed by the closing of inlet and exhaust dampers. After a 15 to 30 minute waiting period, the compressed air and timing circuit should be shut off along with any auxiliary equipment.

- The hopper(s) should be emptied of material before the airlock and/or screw conveyor is turned off. This step will reduce the chance of dust hangup and plugging due to compaction and sticking of the dust in condensing atmospheres.

4.2.3.2 Specific Start-up Procedure for a Reverse Air Baghouse Used for the Collection of Coal Fly Ash (170)--

The basic philosophy during start-up is to prevent flue gas from the coal-fired boiler from entering the baghouse until the baghouse is completely preheated and the bags precoated. These precautionary steps minimize penetration of fine particles into the fabric structure, thereby reducing the chance of premature filter plugging or blinding. Prior to actual start-up, the system is checked out to verify that all control elements, dampers, and fans are functioning correctly. Additionally, contractor and user personnel should jointly develop the system start-up regimen.

The specific installation whose start-up procedures are discussed below consisted of two coal-fired boilers plus an auxiliary gas-fired boiler. The ductwork was arranged so that the baghouse could be bypassed and there were special dampers provided so that the clean flue gas from the a gas-fired boilers could be used for preheating the individual baghouse compartments. In the event that a gas-fired unit is not available, baghouse preheating options might entail electrical tracing, steam coils, or a specially designed auxiliary gas heater whose effluent can be directed into one or both boilers until temperatures exceed the dew point of the flue gas. The time required to reach safe (above dew point) temperatures will depend mainly on the heat rate and disposition of heating surfaces. A paraphrased version of the first hand reporting of start-up procedures and their results for the coal- and gas-fired boilers discussed above is presented in the following paragraphs.

Step No. 1--Preheat Compartments Using Hopper Heater--Electrical strip heaters located in the collector hoppers were turned on while the compartment inlet dampers remained open and the compartment outlet and reverse air dampers were closed. This step elevated compartment temperatures to only 90°F, considerably below the 125°F sought to exceed the water dew point. Insufficient heating was attributed to low (November) ambient temperatures.

Step No. 2--Preheating of Inlet Duct with Flue Gas from Gas-Fired Boiler--Damper arrangements for these systems permitted the clean flue gas from the gas-fired boiler to be directed into the inlet duct leading to the coal-fired boiler baghouse. By opening the by-pass damper immediately before the inlet to the baghouse, the effluent from the gas-fired boiler could be used to preheat the inlet duct up to the bypass damper, thus reducing the system heat loss when the coal-fired baghouse was brought on-line. The entering gas temperature was estimated to exceed 300°F.

Step No. 3--Preheating the Baghouse with Hot Flue Gas--The flue gas from the gas-fired boiler was then directed through two baghouse compartments at a time, by closing the proper bypass dampers and opening the compartment outlet dampers. This process was continued until the entire baghouse was heated to 275°F, a temperature considered high enough to minimize condensation problems.

Step No. 4--Precoating of Bag Surfaces--The bags were precoated by injecting fly ash pneumatically into the inlet duct so that an areal density of about 0.2 lb per square foot was attained over a 1 1/2 hour period. The fly ash was trucked to the plant from a local coal burning utility.

Step No. 5--Verification of Precoat Effectiveness--Visual inspection of the filtration surface through an open hopper access door with the aid of a bright light source indicated that the bags were coated over their full length. It was anticipated that this surface precoat would capture most of the fine and potentially plugging combustion products that exist before steady state combustion has been achieved.

Step No. 6--Admission of Flue Gas to Baghouse--Compartment isolation dampers were opened so that normal filtration could commence. It had been previously established, Step No. 5, that an adequate precoating of the fabric surface had been accomplished so that any sooty combustion products would be filtered out by the surface dust layer rather than penetrating the underlying fabric. Because the boiler was operating at roughly 1/4 capacity a very low pressure loss across the bag was indicated.

4.2.4 Troubleshooting (161-166,168,169)

The tracing and correcting of fabric filter problems requires a detailed baghouse inspection by the plant operator, possibly with the assistance of the baghouse manufacturer. As indicated in the previous section (Table 12), many problems have more than one cause and hence will require a combination of corrective actions (167-172). Although the air pollution inspector may never participate in a detailed baghouse inspection, familiarity with inspection procedures and remedial measures employed by the user/manufacturer team can add greatly to his overall knowledge and understanding of the fabric filter system. The adequacy of a fabric filter system is demonstrated, for the most part, by a cleanliness of the exhaust air stream and a moderate pressure loss across the fabric (161). This assumes that the gas flow requirement is satisfied and that annualized costs and maintenance requirements are acceptable. The quality of the stack emissions and the collector pressure loss characteristics, both of which are readily determinable by enforcement agency personnel, will provide a practical assessment of system operation.

Very low pressure losses may signify damaged (leaking) bags and/or fabric overcleaning, both of which may lead to reduced collection efficiency. On the other hand, high fabric pressure loss, while often an index of high collection efficiency, may reflect an undersized baghouse and/or insufficient cleaning.

4.2.5 General Preventive Maintenance, Including Bag Replacement and Cleaning (161)

Any preventive maintenance schedule must include periodic inspections of all system components. The following discussion, which addresses the more important items requiring careful maintenance, is followed by a system maintenance checklist.

4.2.5.1 Care of Filter Media (162-166)--

Fabric selection will vary widely depending on such factors as temperature, humidity, chemical characteristics of the dust or gas stream, and general operating and cleaning procedures (45,50-53). The fabric manufacturer should be consulted regarding care and use of the fabric, washing, patching, and selection of replacement bags. Readjustment of fabric tension, which is usually recommended within 2 weeks after start-up, should be checked periodically thereafter (123). Regular bag inspections should also be made to ensure that the fabric is not blinding. Abnormal increases in pressure loss across the fabric may signal a blinding (or plugging) problem. Bags should also be checked regularly for loose clamps, torn or worn spots, excessive slackness, or other potential sources of faulty performance. Pin holes and small tears can occasionally be mended, but the permanence of such repairs depends upon the patching material, the type of fabric, the operating environment, and, in particular, the skill of the repair person.

One manufacturer (168) recommends that a cost analysis be performed to determine whether bag cleaning (outside of the baghouse) or bag replacement is the more economical approach. If bag cleaning appears acceptable, it is recommended that bags be carefully removed from the collector housing and first thoroughly vacuum-cleaned. If vacuuming alone is not sufficient to restore bags to an operable condition, the following laundering and patching procedures can be undertaken:

- Natural Filter Fabrics (Wool and Cotton)--All wool and cotton fabrics are subject to shrinkage when washed in water. Since the result may be poorly fitting bags, it is advised that cleaning be performed by conventional dry cleaning processes with pure organic solvents. Dry cleaning detergents and additives that permit addition of water to the solvent may cause shrinkage of wool felt. Wherever possible, drying should be carried out by hanging in drying rooms rather than in tumblers. Addition of surfactant to the cleaning solvent (2 to 3 percent by weight) will help in restoring the structure of both natural and synthetic fabrics.
- Synthetic Filter Fabrics (e.g., Polyester, Polypropylene, Nomex)--Most synthetic media can be washed in water without shrinkage provided that the water temperature does not exceed 140°F and a mild soap such as a dish washing detergent is used. Again, bags should

be hung in drying rooms to avoid the creasing and twisting associated with tumble drying. Drying temperatures should also be maintained at moderate levels (less than 150°F) to prevent fiber shrinkage. Some synthetic products, however, are best restored by dry cleaning with Stoddard's solvent that will not damage most synthetics.

After the bags are completely dried they should be inspected for defects by viewing the surface while illuminated from the opposite side. Thin spots or holes, which are clearly indicated by the above technique, are marked for emergency repair, the latter consisting of patching the inside surface of the bag, with a combination of perimeter stitching and sufficient cross-hatch-sewing to secure any loose edges. All patches, as well as the thread, should be of the same material used in the original bag. Because this type of sewing requires heavy duty machines, the work should be performed by a sailmaker or awning company, or by an industrial firm specializing in bag cleaning and repair.

The above repair techniques are suggested mainly for emergency situations. It is often preferable that damaged bags be replaced by new ones since bag life and filtration efficiency for the repaired bags may be reduced.

4.2.5.2 Bag Replacement--

The ideal approach to bag replacement is to renew all fabric in the collector, or at least in an individual compartment at the same time. If only a small fraction of the bags are replaced, air flow through the replacement bags will commence at very high levels, up to 10 times the normal rate. The result will be greatly increased local dust penetration and, more importantly, an increased likelihood of fabric plugging or blinding.

Fortunately, any high initial flows through a new bag will soon increase its pressure loss to the level of the remainder of the bags. Thus, despite the problem potential, individual bags can usually be replaced without impairing system function. An exception occurs, however, when very abrasive dusts are collected by abrasion-sensitive media, e.g., cement clinker dust and glass bags. Here, high velocities near the inlets (thimble end) of new bags can cause severe abrasion in a very short time.

Constant advancements in filter media technology make it worthwhile to maintain contact with the manufacturer. As new fibers and fabrics become available, the manufacturer is in the best position to offer advice and suggestions for improving media performance and service life (167-172).

Replacement filter media should be obtained from, or ordered through, the original equipment manufacturer. If a different medium is considered, consult the collector manufacturer and obtain his approval for the substitute material. Changing to an unapproved fabric may lead to serious operational problems and also void manufacturer guarantees.

4.2.5.3 Valves and Dampers (161-166,167-172)--

Most baghouses require valves or dampers for isolating individual compartments during cleaning and for regulating the discharge of the collected material from the dust hopper. The proper operation and maintenance of the dampers or valves including lubrication and avoidance of dust caking and corrosion is basic to effective collector performance. It is also important that the manufacturer's recommendations be incorporated in the user's maintenance schedule. Valve and damper motion is often detected by the sounds of opening and closing, pressure loss changes across isolated compartments, and the observed motion of external drive mechanisms.

4.2.5.4 Motors, Fans, and Belts (167-172)--

Motors require periodic inspection and lubrication with the frequency depending on the type of motor, type of bearings, and severity of service. Fans should be checked especially for tightness of all bolts, bearing vibration, noise, or signs of bearing wear.

The following guidelines are offered to estimate what constitutes excess vibration in terms of the observed amplitude (161).

Fan Speed	Vibration Amplitude mils			
rpm	Smooth	Fair	Rough	Very rough
600	2	4	8	15-20
900	1.5	2.75	6	8-10
1200	1.0	2.0	4.5	6-8
1900	0.75	1.5	3.5	5-7

1 mil = 0.001 inches

Fan housings and wheels (impellers) should be inspected for wear and accumulations of dust and dirt. Cleaning thoroughly with a steam or water jet and compressed air or wire brush will prevent fan imbalance. Bearings should be shielded so that water and dust will not penetrate the pillow block during cleaning. Fan wheels with badly worn blades, flanges, or collars should be replaced or rebuilt and rebalanced. Consult the fan manufacturer in such a situation. Since bearings on high speed fans are often designed to operate between 100° and 200°F, do not replace them merely because they appear to be running hot. Check the temperature of the pillow block with a thermometer and compare with the fan manufacturer's written recommendations. If the motor requires factory repair, it is usually the motor manufacturer and not the baghouse manufacturer who provides this service.

A large fan is usually driven by an electric motor through a V-belt drive that requires proper belt tensioning to prevent undue slippage or unnecessary stress on the fan bearings. If belts squeal at start-up, they are too loose and should be tightened. New belts often require a period of 1 to 2 months running-in time before final tensioning is accomplished. Worn belts should be replaced by matched sets of spare V-belts that should be maintained in company stock. Sheaves should be replaced when the grooves become sufficiently worn to allow slippage or cause belt abrasion.

4.2.5.5 Ductwork (161-166)--

Proper performance of a dust collection system is only attainable with frequent inspections and/or maintenance of the housing, ductwork, hoods, hopper, and dust removal system. Periodic inspections of the ductwork should be made to ascertain that sufficient gas velocity is maintained throughout the system to prevent dust settlement. Generally, a velocity of 4000 ft/min is recommended for horizontal runs whereas 2000 ft/min is usually sufficient in vertically aligned ducts.

The duct system including supporting structures should be protected against physical damage due to impact, vibration, and abrasion. Any sections damaged sufficiently to interfere with gas flow or to cause leakage should be repaired immediately or replaced. Frequent inspections and maintenance are required to keep the duct system in good operating condition.

4.2.5.6 Auxiliary Systems--(167-172)

Compressed air systems must be installed and operated in accordance with good engineering practice with aftercoolers, automatic condensate traps, and filters included where their use is indicated. Special situations such as very low ambient temperatures will require thorough drying and/or heating to prevent freezing (168,169).

The instructions concerning maintenance and operation of valves whether they be pneumatically or electrically driven must be followed closely. Pneumatically driven units often require special treatment of the compressed air supply such as filtration, dewatering, addition of lubricant, or antifreeze.

4.2.5.7 Maintenance Checklist (161)--

As with start-up, preventive maintenance depends on the type of collector and the recommendations regarding inspection frequency provided by the equipment manufacturer. A composite listing of 10 items or conditions to be regularly checked for different types of baghouses is provided below (167-172).

- Inspect filter media for blinding, leakage, wear, slack, bag tension, loose bag clamps, or discoloration. If the collector is a reverse jet design, fabric discoloration may indicate blower problems. Additionally, check the contact surface of blowrings for dust encrusation.

- Inspect the inside surface of reverse jet system blowrings for burrs, scaling, clogged slots, or indications of bag chafing. Check blowrings for leaks and examine for signs of deterioration. Routinely lubricate the blower and inspect for hot spots or increases in vibration and noise. It is pointed out that reverse-jet systems, Appendix D, Figure D-1, are gradually being replaced by the more effective pulse jet devices.

- Inspect overall collector and compartment housings, hooding, and connecting ductwork for leakage, corrosion, or dust accumulation.
- Check all solenoid-operated pneumatic damper actuators, airlocks, and valves for proper seating, dust accumulation, leakage, synchronization, and operation.
- Check hopper discharge for possible bridging of dust.
- Determine regularly the bag pressure drop and compare frequency of cleaning with that recommended by the manufacturer.
- Inspect fans for tightness of bolts, bearing vibration and temperature, erosion or dust buildup in housing and on wheel, alignment of fan impeller with V-belt drive or coupling and driver, and sheave appearance for signs of V-belt wear.
- Inspect all bearings on fans, motors, dampers, etc. for lubrication and free rotation. Follow manufacturer's instructions since overlubrication must be avoided.
- Check foundation (footing or sill) bolts on collector, motor, fan, etc. for tightness as well as bolts on collector housing and structural members.
- Check access door(s) for leakage due to faulty gaskets or warping of door(s) and/or frame(s).

For the above-stated items, the inspection frequency will depend on the vendor's recommendations for a particular system, the standards in effect at the user's plant, and the severity of the operating environment. Examples of recommended inspection intervals, however, for some of the major filter system components are provided in Table 13 (167-172). Whereas Table 13 reflects vendor experience, the maintenance schedules cited in Table 14 are based upon a special polling of filter users by the authors of this handbook. Despite the diverse collector types represented in Table 14, one common facet should be noted. Isolation valves and dampers (Item 7), bags (Item 8), and the baghouse structure (Item 13) all show widely varying inspection periods. This may explain why these components experience the greatest problem frequency, as pointed out in the previous section.

4.3 INSPECTIONS PERFORMED BY AIR POLLUTION AGENCIES

4.3.1 Types of Inspections

Baghouse inspections by air pollution control agencies may be performed for any one of the following reasons: compliance determination, complaint investigation as a result of excess emissions or equipment malfunction, source registration/plan approval, permit review/renewal, and special studies (i.e., operating and maintenance evaluations or updating emission inventories). The type and purpose of the inspection will determine (a) the extent of

TABLE 13. TYPICAL MAINTENANCE SCHEDULE FOR A FABRIC FILTER SYSTEM 167-172

Inspection frequency	Component	Procedure
Daily	Stack and opacity meter	Check exhaust for visible dust.
	Manometer	Check and record fabric pressure loss and fan static pressure. Watch for trends.
	Compressed air system	Check for air leakage (low pressure). Check valves.
	Collector	Observe all dials, meters, charts, and gauges etc. on control panel and listen to system for properly operating subsystems.
	Damper valves	Check all isolation, bypass, and cleaning damper valves for synchronization and proper operation based upon manufacturer guidelines.
	Rotating equipment and drives	Check for signs of jamming, leakage, broken parts, wear, etc.
Weekly	Filter bags	Check for tears, holes, abrasion, proper fastening, bag tension, dust accumulation on surface or in creases and folds.
	Cleaning system	Check cleaning sequence and cycle times for proper valve and timer operation. Check compressed air lines including oilers and filters. Inspect shaker mechanisms for proper operation.
	Hoppers	Check for bridging or plugging. Inspect screw conveyor flighting for proper operation and lubrication.

(continued)

TABLE 13 (continued)

Inspection frequency	Component	Procedure
Monthly	Shaker mechanism	Inspect for loose bolts.
	Fan(s)	Check for corrosion and material buildup and check V-belt drives and chains for tension and wear.
	Monitor(s)	Check accuracy of all indicating equipment.
Quarterly	Inlet plenum	Check baffle plate for wear; if appreciable wear is evident, replace. Check for dust deposits.
	Access doors	Check all gaskets
	Shaker mechanism	Tube type (tube hooks suspended from a tubular assembly): inspect nylon bushings in shaker bars and clevis (hanger) assembly for wear. Channel shakers (tube hooks suspended from a channel bar assembly): inspect drill bushings in tie bars, shaker bars, and connecting rods for wear.
Semi-annually	Motors, fans, etc.	Lubricate all electric motors, speed reducers, exhaust and reverse air fans, and similar equipment.
Annually	Collector	Check all bolts and welds. Inspect entire collector thoroughly, clean, and touch up paint where necessary.

TABLE 14. TYPICAL FABRIC FILTER INSPECTION AND MAINTENANCE PROCEDURES, USER RESPONSES

Inspection or maintenance procedure	Frequency[a]					
	Daily	Weekly	Monthly	Quarterly	Semi-annually	Yearly
1. Duct inspection for dust settlement (and removal if required)				X		X
2. Bag compartment--painting, patching, regasketing, recaulking						X
3. Supporting structure and framing--painting, bolt tightening, weld inspection						X
4. Heating equipment for baghouse--operating temperature, temperature sensors and controls, insulation	X					
5. Fan drives, electrical motors, gear trains--checks for wear, lubrication	X	X				
6. Repressure fan (for reverse air cleaning) check for temperature and vibration	X					
7. Compartment isolation and bypass dampers--mechanical drive, jamming, leakage	X					X
8. Bag (fabric) inspection, clean side--wear, damage, dust seepage, surface deposits, bag clamps			X	X		X

(continued)

TABLE 14 (continued)

Inspection or maintenance procedure	Frequency[a]					
	Daily	Weekly	Monthly	Quarterly	Semi-annually	Yearly
9. Lubrication of damper valves, shaker mechanisms		X	X			
10. Access doors--jamming, insulation sealing, hinges, safety locks				X		X
11. Hopper--dust level, bridging, transfer valve, material balance on dust recovery	X					X
12. Bag suspensions--frames, drive attachment hooks, tension adjustment system				X		X
13. Baghouse--check for floor deposits, gross leakage		X		X		X
14. Control panel--indicator lights, switch position, dial displays	X					
15. Baffle plate and guide vanes--erosion or dust deposition						X
16. Shaking mechanisms--linkage, slack, amplitude or frequency adjustment						X
17. Compressed air supply--pressure, oil and water separators	X	X				

(continued)

TABLE 14 (continued)

Inspection or maintenance procedure	Frequency[a]					
	Daily	Weekly	Monthly	Quarterly	Semi-annually	Yearly
18. Fire detectors, sprinklers, explosion panels					X	
19. Instrumentation--direct display, continuous monitors						
a. Baghouse temperature	X					
b. Overall baghouse pressure loss	X					
c. Individual compartment pressure loss	X					
d. Fan static pressure	X					
20. Stack emissions--visual estimates, automatic in-stack opacity meters	X					
21. Fabric cleaning controls--timing circuits, pressure sensors	X					

[a] "X" may indicate one or more responses.

preparation for the inspection, (b) whether or not the inspection is announced to the plant beforehand, and (c) the effort and/or time required for conducting it.

Compliance-type inspections (which provide preliminary assessments only since source sampling is the ultimate basis for determining compliance with the emission standard) should usually be unannounced so that the plant can be evaluated under its normal operating conditions. Such indicators as fuel use, continuous monitoring facilities, and visible emissions, that can be estimated during the unannounced inspection, often provide a definitive picture of a plant's manufacturing and fabric filter operations provided that there are no plant access problems or faulty and/or inoperative equipment.

For other inspections pertaining to source registration, construction, plan approval, or permit renewal, the plant should be given sufficient advance notice so that qualified plant personnel can be present to provide the drawings, manuals, and process information that might be required. Prior notice should also be given when performing inspections for special studies designed to document (a) operating and maintenance practices or (b) process and emission data so that the required raw material rates, productivity levels, and stack test information can be readily available. Regardless of the type of inspection to be conducted, pertinent supporting information should be obtained prior to, during, and following the source evaluation.

4.3.2 Procedures

Before conducting any plant inspection, the air pollution control investigator should become thoroughly familiar with the process in question and all agency file data currently on record concerning past inspections, complaints, process upsets, excess emission episodes, or other conferences, submittals, variance requests, or pending regulatory actions concerning the facility. The air pollution engineer or inspector should prepare whatever is necessary in the form of process flowsheets, chronological source history, operating permits, and inspection checklists so that the actual inspection can be made in a concise and orderly manner without overburdening the source personnel. This will serve to promote a good working relationship between the facility and the agency which, in turn, may foster better operating practices on the part of the plant. Based upon knowledge of the process and the type of inspection planned, the inspector may want to evaluate the source during periods of both average and maximum rated throughput so that representative information can be obtained. The evaluation period, which may depend on the time of day, week, or season, may indicate whether advance notice should be given the plant. The type of safety equipment, protective clothing, and measuring or sampling devices required by the inspector will also depend upon the type of inspection. The inspector should know whether hard hats, steel tipped shoes, safety glasses, ear protectors, or special clothing are required and whether they can be provided by the plant. It may also be necessary to provide special sampling or analyzing equipment (manometers, temperature sensors, gas analyzers, etc.) for evaluating process streams or baghouse inlet and outlet conditions.

4.3.3 Inspection Sequence

Upon arrival at the general plant location (but probably beyond plant boundaries), the stack(s) should be observed for visible emissions. With properly operating fabric filters, no visible emissions (less than 5 percent opacity) should be the rule. Periodic puffs may indicate a defective cleaning system, insufficient compartmentalization, too small an interval between cleanings or a defective bag in one compartment. Depending on the plume appearance and whether the inspector is a certified smoke reader, a detailed evaluation by EPA Method 9 may be justified. In addition to monitoring any smoke emissions, the plant environs should be checked for fugitive emissions, dust deposits, or damage to vegetation, any of which may indicate nonoperative or malfunctioning baghouse equipment. After the plant surroundings have been observed for whatever length of time is deemed necessary (10 to 30 minutes or more), the inspector should enter the property.

Once inside the plant, the inspector may be requested to sign one or more forms concerning waivers of liability or confidentiality of process data. While confidentiality agreements, (which are frequently encountered), should be handled according to agency policy and procedures, insurance waivers or other forms that restrict access to certain parts of the plant should not be signed since the inspector has a legal right of entry to all areas under Section 114 of the Clean Air Act. Problems with respect to signing releases or other documents should be referred to Agency (EPA) attorneys.

The purpose and type of the proposed inspection, coupled with the observations made while outside the facility, will suggest whether the process equipment or the baghouse should be inspected first. Reasons for proceeding immediately to the fabric collector would be as follows: observations outside the plant indicate significant stack or fugitive emissions; the inspection is a strict, unannounced compliance-type; plant personnel are suspected of tampering with several facets of the fabric filter operation; or the inspector, because of numerous previous visits to the plant, is very familiar with the process operation, and does not intend to do any extractive sampling.

Reasons for beginning the inspection with the process equipment would be the following: an announced, noncompliance-type inspection is being performed and the inspector is assured that the baghouse will be completely operational, and the inspector is unfamiliar with some process details and would like to observe it before seeing the baghouse in operation.

Regardless of where the inspection begins, once inside the plant (the stack and plant surroundings should always be evaluated prior to entering a facility), the inspector should proceed in a logical sequence from one end to the other. In this manner, the inspector can grasp the total picture and thus have a better appreciation of potential problems, their causes, and possible solutions. Various items to look for during the process stream inspection are noted in the following paragraphs.

4.3.3.1 Process Equipment--

With respect to the industrial or combustion process of interest, the following information should be sought: Raw materials--types, composition, feed rates, toxicity or hazard potential, dust generating capacity, etc;

process type and equipment--method of mixing, reaction conditions (temperature, pressure, etc.), emission potential (emission factors), use of pressurized reaction vessels, kilns, dryers, furnaces, etc; and product--output rate, process monitors.

4.3.3.2 Dust Capture and Transport System--

Use of movable or stationary hoods, capture velocities, dust accumulation, static pressure, condition of cleanout traps, integrity of ductwork, length of runs to baghouse, and leaks or fugitive dust emissions should all be evaluated.

4.3.3.3 Fabric Filter System--

- Parameter monitors--including opacity or broken bag detectors; manometers for pressure drop across fabric, compartments, or entire collector; indicators for cleaning sequence, cycle time, compartments off-line, temperature, volume flow, air-to-cloth ratio, moisture, pulse-jet header pressure, and reverse air flow.

- Baghouse exterior--cleaning system operation; cleaning method; overall condition of exterior housing, including structural members, access doors and gaskets, reverse air fan operation, and shaker mechanism. Visual evidence of corrosion; warping of panels; faulty or missing gasketing; loose bolts; and noise, odor, or elevated temperatures as indicators of worn bearings, overstressed fan belts and electric motor problems are identifiable by external inspection.

Baghouse interior (if interior inspection is deemed necessary and is feasible)--condition of bags: tears, pinholes, and sagging (inadequate tension). In the case of a sagging or slack bag, a folding of the bag over the bottom thimble connection creates a pocket in which accumulated dust can rapidly abrade and tear the fabric. Slackness also prevents effective cleaning action with both reverse flow or mechanical shaking systems. Dust seepage or bleeding and/or pinhole leaks are evidenced by dust deposits on the "clean" side of the fabric. Staining and stiffening of the dirty fabric indicates excessive caking caused by moisture condensation or chemical reactions. The latter condition leads to fabric blinding and excessive pressure loss as well as to fabric failure. More than a 1/4 inch dust layer on floor plates or isolated piles of dust suggest excess seepage and/or torn or missing bags.

Inspection of the inlet plenum, including bag interior, will reveal any excess dust buildup on bags and distribution plates. If the amount of dust on a bag after cleaning is more than twice the weight of the new (unused) bag, insufficient cleaning is indicated. The condition of solenoid valves, poppet valves, mechanical linkages, bag clamps are also indicated.

- Special attention is directed to the many possible safety hazards associated with interior baghouse inspections. These may include, but are not limited to, asphyxiants, high concentrations of toxics, high air temperatures, hot surfaces, and numerous physical hazards. In the latter category are mechanical obstacles, contact with sharp objects, falling objects, electrical shock due to exposed wires or improper grounding, etc. all of which are accenuated because of poor illumination within most baghouses. General EPA policy is to strongly advise against entering baghouses unless absolutely necessary. Given the latter situation, the inspector should (a) be accompanied by an experienced person who is fully aware of the potential hazards and (b) observe all safety regulations with respect to working in confined spaces, wear protective clothing and respiration equipment (SCBA or air supply and work with lifeline) and outside partners with proper tagging for "inspection-in-progress" and with all machinery and dampers locked into the "off" mode while the baghouse interior is occupied.

4.3.3.4 Fan--

Location--clean or dirty side--static pressure, rotation rate, amperage, housing temperature and condition, excessive noise or vibration, condition of belts.

4.3.3.5 Dust Disposal System--

Condition of hoppers, presence of insulation, level indicators, vibrators, adequacy of dust removal, fate of dust.

Various inspection locations in the previous five areas may or may not be required depending on overall plant conditions, type of inspection, whether the plant is operating, or if extractive sampling is to be performed. For example, unless absolutely necessary, the plant should not be requested to shut their process/fabric filter system down so that internal inspections of the fan and baghouse can be made. If an internal inspection is required, it is usually advisable to wait for a scheduled plant shutdown.

Aside from performing inspections of process and control equipment and their methods of operation, the air pollution control officer should also be concerned about the long-term effects of equipment operation and maintenance for which regulations may or may not be in force. (Some states have regulations that require submittal and approval of standard operating and maintenance procedures for all control equipment.) The inspector investigating these procedures should request to see equipment operation and maintenance logs to evaluate such entries as location of failed bags, bag replacement frequency, cause of bag failure (blowout, tears, chemical attack, abrasion, pinholes), where on the bag failure usually occurs (top, middle, at the cuff, along the seam), or other types of recurring problems with the system that may be suggestive of a trend that should be carefully watched. It should also be noted whether spare parts (bags and associated accessories such as clamps, J-hooks, springs, rings, cages, etc., and fan belts motors, gaskets, bearings, solenoid valves, etc.) are kept on hand or whether the plant must order new parts each time service is required. Accurate recordkeeping, which is a vital part of a good preventive maintenance program, can greatly aid the baghouse manufacturer in solving field problems. Although it is usually recommended that the user follow the manufacturer's guidelines regarding inspection and maintenance frequency, it is not uncommon to find plant logs reflecting deviations from vendor-recommended practice after the system has been operated for a sufficient period of time. In some cases, it may be advisable to consult with firms providing fabric analysis services as a troubleshooting measure. Many such groups are listed in consultant directory sections of the Journal of the Air Pollution Control Association and Pollution Engineering.

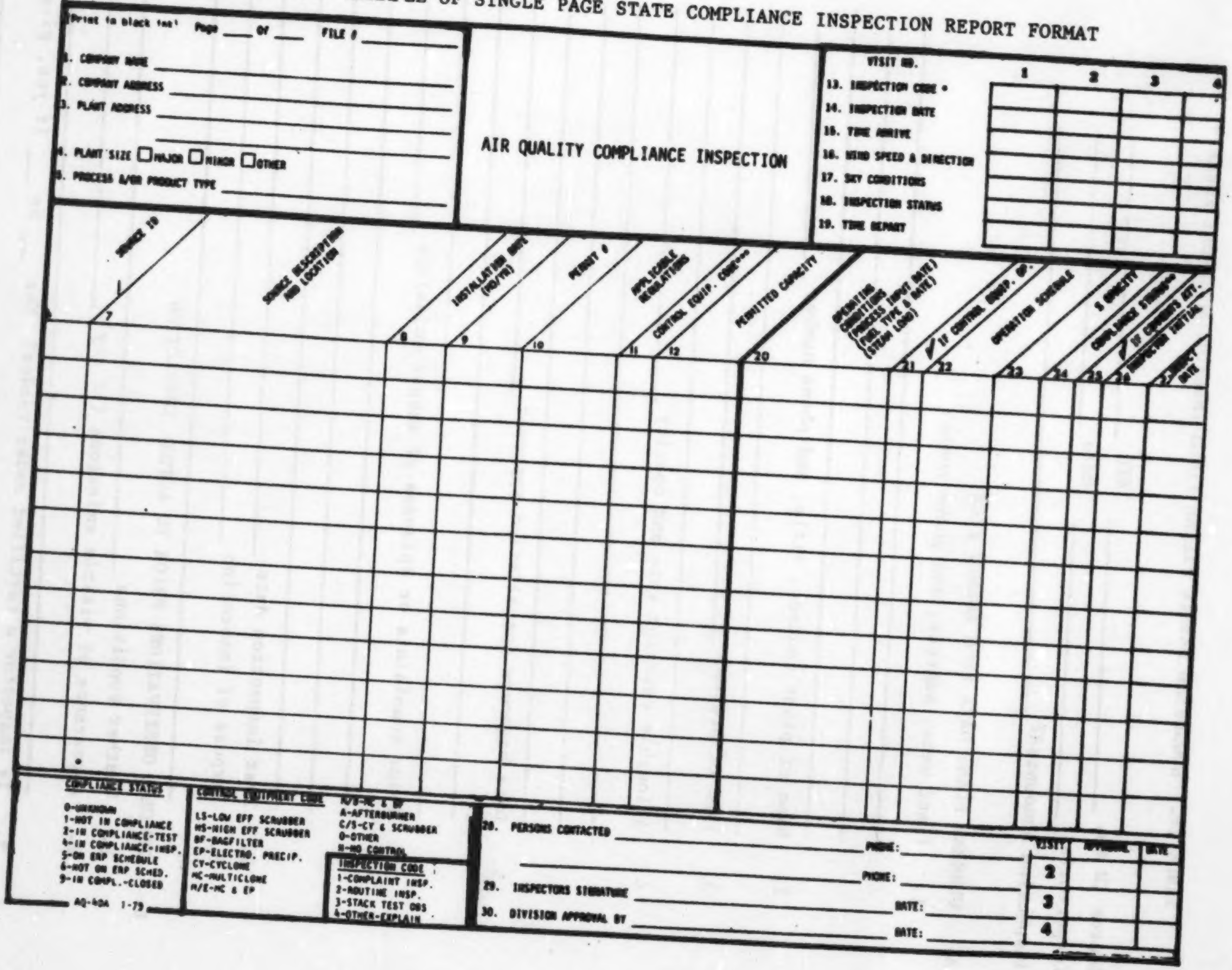
4.4 INSPECTION REPORT FORMAT

The specific format of an inspection report designed to record all of the previously mentioned information would be formidable indeed. In an effort to minimize the length of such documents, some states have devised one-page forms for recording only the most important information. One State, for example, uses the form shown in Table 15 to record pertinent source information obtained during a compliance inspection. It is not likely, however, that a single page form will provide sufficient source information to fully document process and control equipment operation for later referral or emergency use. As a compromise between an overly lengthy inspection form and the one-page form acceptable for certain compliance investigations, the format provided in Table 16 is suggested. This format presents information in a logical sequence that can be modified so that more detailed information about the process, the baghouse, the fan, and the operating and maintenance aspects can be provided by appending additional pages to individual sections. In this manner, different portions of the form can be completed at different times, either at the agency office or at the plant. Specific pages can be inserted, detached, and/or replaced as the situation changes. Whatever type of form is adopted, it should be concise, while still allowing the recording of detailed information when required.

4.5 EXAMPLE INSPECTION REPORT

Based upon an earlier plant inspection for compliance purposes, we have presented results of actual field observations at a gray iron foundry in which the performance of two fabric filter systems was appraised, Table 17. Although more data would have been preferred, the responses typify the information needed to assess the adequacy of existing air cleaning equipment and to point out system deficiencies requiring correction. Data that might reveal plant identity including name, geographical location and product line have been altered to maintain confidentiality. Although field observations suggested compliance with visible emissions criteria, it appeared that the plant's intention to install an inertial precleaning device might help to extend bag service life by preventing large, abrasive particles from reaching the bag surfaces.

TABLE 15. EXAMPLE OF SINGLE PAGE STATE COMPLIANCE INSPECTION REPORT FORMAT



(Print in black ink) Page ____ of ____ FILE # ____________

1. COMPANY NAME ____________
2. COMPANY ADDRESS ____________
3. PLANT ADDRESS ____________

____

4. PLANT SIZE ☐ MAJOR ☐ MINOR ☐ OTHER
5. PROCESS &/OR PRODUCT TYPE ____________

AIR QUALITY COMPLIANCE INSPECTION

VISIT NO.	1	2	3	4
13. INSPECTION CODE *				
14. INSPECTION DATE				
15. TIME ARRIVE				
16. WIND SPEED & DIRECTION				
17. SKY CONDITIONS				
18. INSPECTION STATUS				
19. TIME DEPART				

SOURCE ID	7 SOURCE DESCRIPTION AND LOCATION	8 INSTALLATION DATE (MO/YR)	9 PERMIT #	10 APPLICABLE REGULATIONS	11 CONTROL EQUIP. CODE**	12 PERMITTED CAPACITY	20 OPERATING CONDITIONS (PROCESS INPUT RATE) (FUEL TYPE & RATE) (STEAM LOAD)	21 ✓ IF CONTROL EQUIP. OP.	22 OPERATION SCHEDULE	23 % OPACITY	24 COMPLIANCE STATUS***	25 ✓ IF COMMENTS ATT.	26 INSPECTOR INITIAL	27 INSPECT DATE

COMPLIANCE STATUS

0-UNKNOWN
1-NOT IN COMPLIANCE
2-IN COMPLIANCE-TEST
4-IN COMPLIANCE-INSP.
5-ON ERP SCHEDULE
6-NOT ON ERP SCHED.
9-IN COMPL.-CLOSED

AQ-40A 1-79

CONTROL EQUIPMENT CODE

LS-LOW EFF SCRUBBER
HS-HIGH EFF SCRUBBER
BF-BAGFILTER
EP-ELECTRO. PRECIP.
CY-CYCLONE
MC-MULTICLONE
M/E-MC & EP
M/B-MC & BF
A-AFTERBURNER
C/S-CY & SCRUBBER
O-OTHER
N-NO CONTROL

INSPECTION CODE

1-COMPLAINT INSP.
2-ROUTINE INSP.
3-STACK TEST OBS
4-OTHER-EXPLAIN

28. PERSONS CONTACTED ____________ PHONE: ____________

____________ PHONE: ____________

29. INSPECTORS SIGNATURE ____________ DATE: ____________

30. DIVISION APPROVAL BY ____________ DATE: ____________

VISIT	APPROVAL	DATE
2		
3		
4		

TABLE 16. SUGGESTED FABRIC FILTER FIELD INSPECTION REPORT FORMAT*

Source ID No. ______________________ SIC ______________________

Inspector(s) ______________________ Date ______________________

Inspection Announced? ______________________________________

A. GENERAL PLANT DATA FROM AGENCY FILE

1. Plant name, address, and phone number
____
____
____

2. Name of plant contact, title, and phone number ______________
____

3. Type of process ______________________________________
____

4. Allowable emission rate and opacity ____________________
____
____
____

5. Date baghouse installation approved ____________________
____
____

6. Prior complaints or episodes of excess emissions __________
____
____
____

7. Last inspection date ______________________________
8. Purpose of inspection ______________________________
____

B. GENERAL OBSERVATIONS PRIOR TO ACTUAL INSPECTION

1. Weather conditions ______________________________
2. Appearance of visible emissions (if any) ________________
____

3. Is inspector a certified smoke reader? Yes ___ No ___ If yes, give certification date ______________________________
(Attach copy of Method 9, if performed)

TABLE 16 (continued)

C. PROCESS INFORMATION

1. Confidential? Yes ___ No ___
2. Person supplying process information and title ___
3. Product(s) produced ___
4. Production rate(s) ___
5. Raw materials used ___
6. Portion of process controlled by baghouse ___
7. Average uncontrolled emission rate or concentration (indicate whether obtained from stack test, mass balance, AP-42 emission factor, other, etc.) ___
8. Date of last stack test and average emission rate obtained ___
9. Is cleaned effluent recirculated back into plant? Yes ___ No ___

D. DUST CHARACTERISTICS (PRIOR TO CONTROL)

1. Is materal toxic or otherwise hazardous or does it require special handling? Yes ___ No ___ Describe ___
2. Moisture content or other gaseous constituents ___
3. Abrasiveness or other properties ___
4. Particle size data - indicate how measured ___

TABLE 16 (continued)

E. COLLECTION SYSTEM(S)

1. Baghouse #1 #2 #3
   - a. Manufacturer
   - b. Type or trade name
   - c. Model No.
   - d. No. of compartments
   - e. Bags/compartment
   - f. Bag l x d
   - g. Total Cloth Area
2. Fan #1 #2 #3
   - a. Manufacturer
   - b. Model No.
   - c. Blade type
   - d. Belt or direct drive
   - e. Power rating
   - f. Positive or negative pressure
3. Fabric #1 #2 #3
   - a. Manufacturer
   - b. Material
   - c. Woven or felted
   - d. Weave
   - e. Weight
   - f. Permeability
   - g. Operating temp. range
   - h. Surface treatment
   - i. Coating upon startup
   - j. Guaranteed life
   - k. Actual life
4. Cleaning System #1 #2 #3
   - a. Method
   - b. Freqnency
   - c. Actuated by
   - d. Anticollapse rings
   - e. Wire mesh cages

TABLE 16 (continued)

F. DUST HANDLING SYSTEM(S)

1. Do baghouse hoppers have:
    - a. Heaters
    - b. Insulation
    - c. Level indicators
    - d. vibrators
2. Type of dust transport system
3. Fate of collected material

G. INSTRUMENTATION

Do system monitors record any of the following:

1. Process start-up/shutdown
2. System flow or velocity
3. Fan motor amps
4. Temperature (recording?)
5. Pressure
6. Opacity
7. Outlet emissions
8. Compartments off-line
9. Compartments being cleaned
10. Compartments in operation
11. Other

H. OPERATING PARAMETERS - DESIGN AND ACTUAL

	Design	Actual
1. Flow rate		
2. Pressure drop, flange-to-flange measurement location		

TABLE 16 (continued)

3. **A/C, gross** ____________________

4. **A/C, net**
(2 compartments off-line) ____________________

5. **Temperature (Baghouse)** ____________________

6. **Efficiency** ____________________

7. **Emission rate** ____________________

8. **Opacity** ____________________

I. OPERATING EXPERIENCE/MAINTENANCE ASPECTS

1. **Percent of time baghouse fully operational when process is in operation** ____________________

2. **Has a detailed maintenance schedule been instituted?** ____________________

3. **Is maintenance schedule as recommended by baghouse manufacturer or by plant?** ____________________

4. **Are maintenance records available for inspection?** ____________________

5. **How long are records kept on file?** ____________________

TABLE 16 (continued)

6. Which of the following problem areas have led to periods of excess emissions or caused the process to be shut down?

	Problem Area	Duration	Frequency
a.	Insufficient dust pick-up and/or transport (fugitive emissions)		
b.	Duct abrasion or corrosion		
c.	Temperature excursions, high or low		
d.	Moisture		
e.	Fan abrasion, vibration, etc.		
f.	Gross bag failure		
g.	Inadequate bag tension		
h.	Bag chafing or abrasion		
i.	Pressure loss		
j.	Compartment isolation dampers		
k.	Cleaning mechanism		
l.	Visible emissions		
m.	Plugged hoppers		
n.	Hopper fires		
o.	Dust discharge system		

J. CONCLUSIONS/RECOMMENDATION

1. Compliance status ______________________________
2. Need for further action ______________________________
3. Corrective actions to be taken ______________________________

TABLE 16 (continued)

4. **Time required to rectify problems** ______________________

____

____

5. **Special waivers or review of compliance criteria required** ________

____

____

6. **Need for follow-up inspection** ______________________

____

____

7. **Inspector's signature** ______________________

date ______________________

approved by ______________________

title ______________________

K. **OTHER NOTES, COMMENTS, SKETCHES (ATTACH ADDITIONAL PAGES, IF NECESSARY)** Schematic drawings showing locations of process and dust control equipment should be prepared, particularly so, where verbal descriptions may lead to misunderstandings. Locations should be noted for observed leak sites, evidence of corrosion, warped panels, and other mechanical defects.

TABLE 17. EXAMPLE FABRIC FILTER FIELD INSPECTION REPORT

Source ID No. 2248 SIC 3531
Inspector(s) John Smith Date 12/14/82
Inspection Announced? Yes

A. GENERAL PLANT DATA FROM AGENCY FILE

1. Source name, address, and phone number
   XYZ Casting Co.
2. Name of plant contact, title, and phone number Robert Smith,
   Vice President of Operations
3. Type of process Gray iron foundry
4. Allowable emission rate and opacity
   cupola - 41 lb/hr and 25 percent
   2-shot blast systems - 14 lb/hr and 40 percent
   10 grinding booths - 5 lb/hr and 40 percent
5. Date baghouse installation approved
   System 1 - 9-14-78
   System 2 - 6-12-75
6. Prior complaints or episodes of excess emissions
   None
7. Last inspection date 10-12-81
8. Purpose of inspection to document operating and maintenance practices

B. GENERAL OBSERVATIONS PRIOR TO ACTUAL INSPECTION

1. Weather conditions clear sky, wind 5-10 mph
2. Visible emissions periodic puffs, overall opacity less than 10 percent
3. Is inspector a certified smoke reader? Yes X No ___ If yes, give certification date 11/17/82

TABLE 17 (continued)

C. PROCESS INFORMATION

1. Confidential? Yes ___ No X
2. Person supplying process information and title John Doe, Plant Engineer
3. Product(s) produced heavy machinery castings
4. Production rate(s) cupola - 30 ton/hr, shot blast - 16 ton/hr, grinding booth - 16 ton/hr
5. Raw materials used foundry returns, scrap metal, pig iron, coke, and limestone
6. Portion of process controlled by baghouse
   System 1 - Shot blasting (two chambers)
   System 2 - Grinding (ten booths)
7. Average uncontrolled emission rate or concentration (indicate whether obtained from stack test, mass balance, AP-42 emission factor, other, etc.) (See Notes 1, 2, and 3 at end of report)
   Grinding booths - 64 lb/hr
   Shot blast system - 364.25 lb/hr
8. Date of last stack test and average emission rate obtained
   No previous sampling measurements
9. Is cleaned effluent recirculated back into plant? Yes ___ No X

D. DUST CHARACTERISTICS (PRIOR TO CONTROL)

1. Is materal toxic or otherwise hazardous or does it require special handling? Yes ___ No X Describe ___
2. Moisture content or other gaseous constituents
   low moisture
3. Abrasiveness or other properties
   both systems - highly abrasive
4. Particle size data - indicate how measured
   MMD 2 m (estimate)

TABLE 17 (continued)

E. COLLECTION SYSTEM(S)

1. **Baghouse**	#1	#2	#3
a. Manufacturer	Pangborn	Wheelabrator-Frye	
b. Type or trade name			
c. Model No.			
d. No. of compartments	10	15	
e. Bags/compartment	200	101	
f. Bag l x d	12' x 8" ID	12' x 6" ID	
g. Total Cloth Area	50,265 ft^2	28,571 ft^2	

2. **Fan**	#1	#2	#3
a. Manufacturer	Buffalo-Forge		
b. Model No.			
c. Blade type	radial		
d. Belt or direct drive	both belt		
e. Power rating			
f. Positive or negative pressure	both negative		

3. **Fabric**	#1	#2	#3
a. Manufacturer	Globe Albany	W. W. Criswell	
b. Material	dacron	glass	
c. Woven or felted	felt	woven	
d. Weave	(needled)	2/2 twill	
e. Weight	16 oz/yd^2	10 oz/yd^2	
f. Permeability	--	32 cfm/ft^2 @ 0.5. in W.C.	
g. Operating temp. range	250°F	500°F	
h. Surface treatment	none	none	
i. Coating upon startup	none	none	
j. Guaranteed life	2 years	1-2 years	
k. Actual life	2-4 years	1-2 years	

4. **Cleaning System**	#1	#2	#3
a. Method	pulse jet	shake	
b. Frequency	every 3 min	every 4 hours	
c. Actuated by	timer	pressure	
d. Anticollapse rings	no	no	
e. Wire mesh cages	yes	no	

TABLE 17 (continued)

F. DUST HANDLING SYSTEM(S)

1. Do baghouse hoppers have -
   - a. Heaters none
   - b. Insulation none
   - c. Level indicators both systems
   - d. vibrators both systems
2. Type of dust transport system pneumatic
3. Fate of collected material recycled to respective processes

G. INSTRUMENTATION

Do system monitors record any of the following:

1. Process start-up/shutdown both systems
2. System flow or velocity System 2 only
3. Fan motor amps both systems
4. Temperature (recording?) both
5. Pressure both
6. Opacity both
7. Outlet emissions none
8. Compartments off-line System 2 only
9. Compartments being cleaned both
10. Compartments in operation both
11. Other

H. OPERATING PARAMETERS - DESIGN AND ACTUAL

	Design	Actual
1. Flow rate	System 1 - 151,000 acfm	130 - 150,000
	System 2 - 200,000 acfm	150 - 175,000
2. Pressure drop,	#1 - 4-6 in. W.C.	5-7 in. W.C.
flange-to-flange	#2 - 4-6 in. W.C.	3-5 in. W.C.
measurement location		

TABLE 17 (continued)

		Design	Actual
3.	A/C, gross	System 1 - 7/1	5-6/1
		System 2 - 3/1	2-3/1
4.	A/C, net	#1 - 8/1	same
	(2 comp. down)	#2 - 275/1	same
5.	Temperature	#1 250°F	200-240°F
		#2 500°F	400°F
6.	Efficiency	both - >99%	unknown
7.	Emission rate	both <0.002 gr/scf	unknown
8.	Opacity	both <20%	~5%

I. OPERATING EXPERIENCE/MAINTENANCE ASPECTS

1. Percent of time baghouse fully operational when process is in operation Both systems have operated at >90% availability

2. Has a detailed maintenance schedule been instituted? Yes - for both systems

3. Is maintenance schedule as recommended by baghouse manufacturer or by plant? Maintenance practices originally recommended by baghouse manufacturers have since been modified by plant based on experience.

4. Are maintenance records available for inspection? Yes

5. How long are records kept on file? 5 years

TABLE 17 (continued)

6. Which of the following problem areas have, led to periods of excess emissions or caused the process to be shut down?

Problem Area	Duration	Frequency
a. Insufficient dust pick-up and/or transport (fugitive emissions)		
b. Duct abrasion	System 1 only	numerous occasions
c. Temperature high or low		
d. Moisture		
e. Fan abrasion, vibration, etc.	System 1 only (abrasion)	fairly often 3-4 times/yr
f. Gross bag failure	System 1 only several days before bags replaced	several times/yr
g. Inadequate bag tension		
h. Bag chafing or abrasion		
i. Pressure loss	System 2	infrequent
j. Compartment isolation dampers	up to 8-9 in. W.C.	
k. Cleaning mechanism		
l. Visible emissions		
m. Plugged hoppers		
n. Hopper fires		
o. Dust discharge system		

J. CONCLUSIONS/RECOMMENDATION

1. Compliance Status in compliance with visible emissions and operating and maintenance practices

2. Need for further action none

3. Corrective actions to be taken Plant intends to install cyclone upstream of Baghouse #1 to reduce fabric abrasion by coarse particles

TABLE 17 (continued)

4. Time required to rectify problems about 6 months

5. Special waivers or review of compliance criteria required

None

6. Need for follow-up inspection

Reschedule inspection when cyclone is installed.

7. Inspector's signature

date 12/16/82

approved by

title Chief, Air Control Board

K. OTHER NOTES, COMMENTS, SKETCHES (ATTACH ADDITIONAL PAGES, IF NECESSARY)

The overall inspection revealed that the plant had maintained the baghouses in good condition, although abrasion with respect to the baghouse collecting emissions from the shot blasting operations (metal particles, sand, and broken shot) has been a problem. The plant intends to install a mechanical collector upstream of the fabric filter to capture most of the larger abrasive material. Recordkeeping at the plant was excellent insofar as baghouse operation and maintenance are concerned.

Note 1: Emissions factors for shot blasting and grinding at an iron foundry were obtained from: Gutow, Bernard S. "An Inventory of Iron Foundry Emissions." Modern Casting. January 1972, pp. 46-48. (Emission Factors for these two operations are not provided in AP-42).

Note 2: Shot Blasting--
23.5 ton/hr x 15.5 lb/ton = 364.25 lbhr

Note 3: Grinding--
40 ton/hr x 1.6 lb/ton iron = 64 lb hr

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APPENDIX A

AEROSOL AND SAMPLING TERMINOLOGY

aerosol: A stable cloud of solid particles and/or liquid droplets uniformly suspended in a gas (smoke, fog, mist).

agglomeration: Formation of particle clusters by particle collision due to diffusion and turbulence. Same as coagulation or flocculation.

anemometer: An instrument for measuring gas stream velocity.

attrition: Wearing or grinding down by friction. One of the three basic processes contributing to particle formation, the others being condensation and combustion.

baffle: A plate, grating, or refractory wall used especially to block, hinder, or divert a flow or to hinder the passage of a fluid.

barometer: A detector for measuring atmospheric pressure.

blast gate: A sliding plate or damper installed in a supply or exhaust duct for the purpose of regulating air flow.

bridge: Material blockage across an opening, such as a hopper outlet or pore or flow channel in filter fabric.

cascade impactor: Sampling and particle sizing device in which air is drawn through a series of jets directed against a series of slides or collection stages. Retention of deposited particles may be aided by adhesive coatings. Jet openings are sized to separate dust samples into several size fractions.

ceramic filter: Component of a gas sampling train. These are suitable for high temperature (1000°F) filtration.

coefficient of haze: A measure of light transmission through a soiled filter. Coefficient of haze units are defined as 100 times the optical density as determined by transmittance.

collection efficiency: Percentage of dust collected by a control device.

condensation: The physical process of transforming from a gaseous phase to a liquid or solid state by decreasing temperature, increasing pressure, or both. Gas cooling is the most common technique.

corrosion: Deterioration or physical degradation due to chemical reactions.

counter: Instrument for measuring the number and frequently the size of dust particles in an aerosol.

counting: Determination of the number of dust particles per unit area of a viewing field as with a membrane filter or the number of particles per unit volume of liquid or gas from which airborne particle concentrations can be estimated.

count median size: That particle size for which there are an equal number of particles greater than and less than the median or middlemost size.

cut size: That size particle which can be collected at a specified efficiency, usually 50 percent.

damper: An adjustable gate installed in a duct for the purpose of regulating air flow.

dehumidify: To reduce by any process the quantity of water vapor present in a gas mixture (air).

density: The ratio of the mass of a specimen to the volume occupied by the specimen, the latter often expressed in cubic feet or cubic meters at a fixed gas temperature and pressure.

diameter, aerodynamic: The diameter of a sphere of unit density having the same terminal settling velocity as a particle in question, regardless of its geometric size, shape, and true density.

diameter, count median: See count median size (diameter).

diameter, mass median: That particle diameter for which an equal mass is represented by particles greater than and less than the mass median diameter.

diameter, projected (area): The diameter of a circle having an area equal to that of the projected area of the particle.

diameter, stokes equivalent: The diameter of a hypothetical sphere having the same terminal settling velocity and particle density as the particle of interest, irrespective of its actual size and shape.

dust: Any aerosolized solid material formed by disintegration or attrition processes or redispersed by shearing action (high winds). Sizes range from the microscopic to the macroscopic with the upper size determined by the turbulence in the atmosphere and the source elevation.

dust collector: A device to remove solid particles from a gas stream.

dust counter: An instrument for determining dust particle concentration in a known volume of air. In Aitken's dust counter, condensation is made to occur on the nuclei present by adiabatic expansion of air, and the number of drops are counted. In Owen's dust counter, a jet of humid air is expelled through a narrow slit in front of a microscope cover glass. The pressure reduction due to air expansion after passing through the slit creates a moisture film on the glass impingement surface to which dust adheres for viewing and counting.

dust loading: The weight of solid particles suspended in a fixed air (gas) volume (or its concentration), usually expressed in terms of grains per cubic foot, grams per cubic meter, or pounds per thousand pounds of gas.

electrostatic filter: Filter using electrostatic charge effects to enhance particle capture.

entry loss: Loss in pressure due to air velocity changes caused by duct, hood, and enclosure geometry factors.

erosion: Wearing away due to mechanical or abrading actions..

fines: Particulate matter less than one micrometer in diameter.

fly ash: Finely divided particles of ash entrained in flue gases resulting from the combustion of fuel. The ash particles consist of incompletely burned fuel and a variety of mineral constituents.

fog: Visible aerosols in which the dispersed phase consists of liquid droplets ranging from 5 to 40 μm in diameter and produced by atomization or condensation processes.

fume: Fine solid particles predominantly less than 1 micrometer in diameter, resulting from condensation, sublimation, or chemical reactions, e.g., oxidation of metal vapors.

gas: One of the three states of aggregation of matter, having neither independent shape nor volume and tending to expand indefinitely if not constrained.

geometric standard deviation: The measure of dispersion for a log-normal distribution, the ratio of the 84.13 to the 50 percentile (or the 50 to the 15.87 percentile).

grain: A unit of weight equivalent to 1/7000 of a pound or 65 milligrams.

grit: Solid particles of natural or man-made origin, retained on a 200 mesh screen, roughly 74 μm or greater in diameter.

ground level concentration: The amount of solid, liquid, or gaseous material per unit volume of air, from 0 to 2 meters above the ground.

haze: A state of atmospheric obscuration due to the presence of fine, solid and/or liquid particles in stable suspension; visibility exceeds 1 but is less than 2 km. The particles are so small that they cannot be sensed via impact or thermal effects nor seen with the naked eye.

hood suction: Resultant hood static pressure due to the entry loss plus conversion from fluid potential to kinetic energy.

hopper: Storage container at the bottom of a collection device to hold the dust.

humidity, absolute: The weight of water vapor carried by a unit weight of dry air or gas. Pounds of water vapor per pound of dry air; grains of water vapor per pound of dry air.

humidity, relative: The ratio of the absolute humidity in a gas to that of the saturated gas at the same temperature.

impaction: A particle collision with a collection surface caused by the interaction of inertial and hydrodynamic forces.

isokinetic sampling: Extraction of an aerosol by a sampling probe such that the fluid velocity entering the probe is the same as that at the sampling location in the parent gas stream. Deviation from isokinetic conditions can lead to incorrect estimates of mass particulate concentrations.

manometer: An instrument for measuring pressure differences, usually consisting of a vertically-aligned U-shaped tube containing liquids of known density; e.g., water, oil, mercury. Instrument sensitivity may be increased by changing the angle of inclination.

mass concentration: Concentration expressed in terms of mass of suspended or dissolved material per unit volume of gas or liquid.

membrane filters: Extremely high efficiency filters with relatively low resistance to gas flow that are usually composed of gels of cellulose esters or other polymeric substances. Such filters contain many small holes or pores of controllable size such that their efficiency and pressure loss characteristics may be predicted. In addition, because the filters are usually of high chemical purity, they are well suited for trace metal analyses. Some of the membrane filters can also be rendered transparent, thus permitting direct microscope observation of collected particles. Alternatively, filters can be dissolved in selected organic solvents so that the particles may be isolated and studied. Since most membrane filters are not affected greatly by humidity changes, they can be readily weighed before and after use. They are not suitable for high temperature filtration (except for Teflon membranes) and their electrical charge properties can create sampling and handling problems.

mesh numbers: U.S. sieve sizes designate the number of holes per inch for a specific screen.

Mesh Number	Corresponding Opening, Inches
8	0.093
12	0.066
14	0.055
20	0.0328
30	0.023
40	0.0165
100	0.0058
200	0.0029
325	0.0017

micrometer (micron) (µm): A unit of length corresponding to one thousandth of a millimeter or one millionth of a meter (approximately 1/25,000 of an inch).

mist: A dispersion of relatively small liquid droplets. In meteorology parlance, the term mist applies to water droplets of sufficient size (40 µm) to settle from the air. Persistence of a mist depends upon constant droplet replenishment via condensation processes.

mole: The weight of a substance numerically equal to its molecular weight. If the weight is in pounds, the unit is "pound moles." For dry air at 70°F and a pressure of one atmosphere, there are 29 pounds per pound mole and 386 cubic feet per pound mole (thus a density of 0.075 lbs/ft^3).

opacity: A measurement of visibility as affected by aerosol presence and defined as the apparent obscuration of an observer's vision as compared to that produced by a smoke of a given density rating on the Ringelman chart.

particle: A small discrete mass of solid or liquid matter such as dust, fume, mist, smoke, and fog.

particle (number) concentration: Concentration expressed in terms of number of particles per unit volume of air or other gas.

particle size distribution: Usually refers to a mathematical function or graphical display that describes the mean, median, and range of particle sizes present in a given sampling. A logarithmic normal distribution is most commonly used to represent both atmospheric and industrial aerosols.

particulate matter: Any dispersed matter, solid or liquid, in which the individual particles or agglomerates may range from 0.002 µm up to 500 µm. Particle lifetimes in the suspended state range from a few seconds to several months. Additional terms used to describe particulate matter may include dust, fly ash, smoke, soot, droplets, mist, fog, and fumes.

penetration: That fraction or percent of a particulate material that passes through a dust collector and discharges to the atmosphere.

pitot (static) tube: A device for measuring velocity pressure consisting of two tubes--one serving to measure the total pressure in an air stream (static plus velocity) and the other to measure the static pressure only. By differencing these two pressure signals via manometer or similar device, the static pressure components cancel each other such that only the velocity pressure is displayed.

plume: The visible path formed by the continuous discharge of any aerosol from a stack or chimney. The shape of the path and the particle concentration distribution in the plume is dependent on local meteorological conditions. Looping, coning, fanning, fumigating, and lofting are terms frequently used to characterize plumes.

pressure, atmospheric: The pressure due to the weight of the atmosphere, as indicated by a barometer. Standard sea level atmospheric pressure is 29.92 in. of mercury, 760 mm of mercury, 14.7 psia, and 407 in. water column.

pressure, gage: Pressure referenced to local ambient or atmospheric pressure as a datum. Gage pressure may be indicated by a manometer in which one leg is connected to the pressure source and the other exposed to the ambient atmosphere.

pressure loss: The pressure required to overcome the resistance to gas flow in a system that includes the resistance of straight runs of pipe, entrances to headers, bends, elbows, orifice losses, and pressure drop through gas cleaning devices.

pressure, static: The potential pressure exerted equally in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal to the direction of flow and usually expressed in inches water gage when dealing with air.

pressure, total: The algebraic sum of the velocity pressure and the static pressure (with due regard to sign). In gas-handling systems these pressures are usually expressed in inches water gage.

pressure, velocity: The kinetic pressure in the direction of flow necessary to cause a fluid at rest to accelerate to a given velocity. Usually expressed in inches water gage. (Also referred to as velocity head).

Reynolds number: The dimensionless ratio of inertial to viscous forces in a flow stream. It serves to describe the nature of the flow; i.e., laminar, intermediate, or turbulent.

shape factor: a constant that, when applied to the appropriate characterizing particle diameter, will indicate the total or projected particle surface or particle volume.

smoke: Small gas-borne particles usually resulting from incomplete combustion. Such particles consist predominantly of carbon and other combustible material and are present in sufficient quantity to be observable independently of other solids.

soot: An agglomeration of carbon particles impregnated with "tar" formed by the incomplete combustion of carbonaceous material. These particles, which are much larger than those constituting a true smoke, are highly visible to the naked eye.

specific gravity: A dimensionless quantity defining the ratio of the density of a substance at a given temperature to the density of some reference material (usually water for liquids and air for gases).

specific heat: The heat absorbed (or given up) by a unit mass of a substance when its temperature is increased (or decreased) by one degree. Common units are Btus/lb/°F or Cals/g/°C. For gases, both the specific heat at constant pressure (c_p) and the specific heat at constant volume (c_v) play key thermodynamic roles, particularly so when the flow is compressible.

specific volume: The volume of a substance per unit mass; i.e., the reciprocal of density, usually given in cubic feet per pound or cubic meters per gram.

standard atmosphere: The pressure exerted by a column of mercury 29.92 inches high at 70°F; approximately 14.7 psi. See pressure, atmospheric.

temperature, absolute: Temperature expressed as degrees Rankine or degrees Kelvin where absolute zero corresponds to -460°F or -273°C, respectively.

temperature, dew-point: The temperature corresponding to moisture saturation (100 percent relative humidity) for a given absolute humidity at constant pressure. Any lowering of the temperature will cause water vapor to precipitate as a liquid or solid.

temperature, dry-bulb: The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

temperature, wet-bulb: Wet-bulb temperature is a measure of the moisture content of air (gas). It is the temperature indicated by a wet-bulb psychrometer.

transmissometer: An instrument for measuring the extinction coefficient of the atmosphere for the determination of visibility range. Also called telephotometer, transmittance meter, hazemeter, or smoke density indicator.

velocity, capture: The air velocity at any point in front of the hood or at the hood opening necessary to prevent particulate material and contaminant gases from escaping to the working area.

velocity, terminal settling: That constant velocity at which the fluid resistance to the motion of a body equals the force causing the motion, usually the force of gravity.

velocity, transport (conveying): The minimum air velocity required to transport particulate matter in any air stream, especially confined duct or pipe flows (vertical or horizontal) so that no sedimentation takes place.

velocity traverse: A method for determining the average air velocity in any duct by dividing it into numerous equal area sections. The average velocity then becomes the simple arithmetic average of the velocities measured in each equal area section.

viscosity: The proportionality constant relating shear rate to shear stress that is expressed in units of poise, centipoise, or pounds per foot-second.

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APPENDIX B

PARTICLE SIZE MEASUREMENT (1,6,22,72-74)

Particle size properties are best determined by in situ measurements wherein the number and dimensions of individual particles are sensed by a detection system that does not alter the true size and concentration properties. A few instruments may approach this capability, e.g., single particle light scattering counters (22), but only for very dilute particle concentrations in the respirable range (≤ 3 μm) such as encountered in a clean, ambient atmosphere. Extractive techniques in which the sampled gas stream is drawn through a sampling line and thence through a special membrane filter have limited applications, provided that sampling line losses are negligible and, most importantly, the individual particle deposition density is sufficiently low that the dimensions and form of individual particles can be clearly discerned (71-74).

Both the in situ and extractive methods mentioned above are seldom applicable in real field situations because of various temperature, moisture, and/or pressure problems. Additionally, inlet concentration levels are typically 3 to 5 orders of magnitude greater than can be practically measured by these devices without extensive and highly unreliable dilution techniques. Therefore, the determination of the size properties of high (0.1 to 10 g/m^3) particle loadings is usually made with an instrument called a "cascade impactor," that is available in several commercial designs, Figure B-1 (75-80). With this device, the sampled gas stream is guided sequentially through a series of jet stages that are aligned in the order of

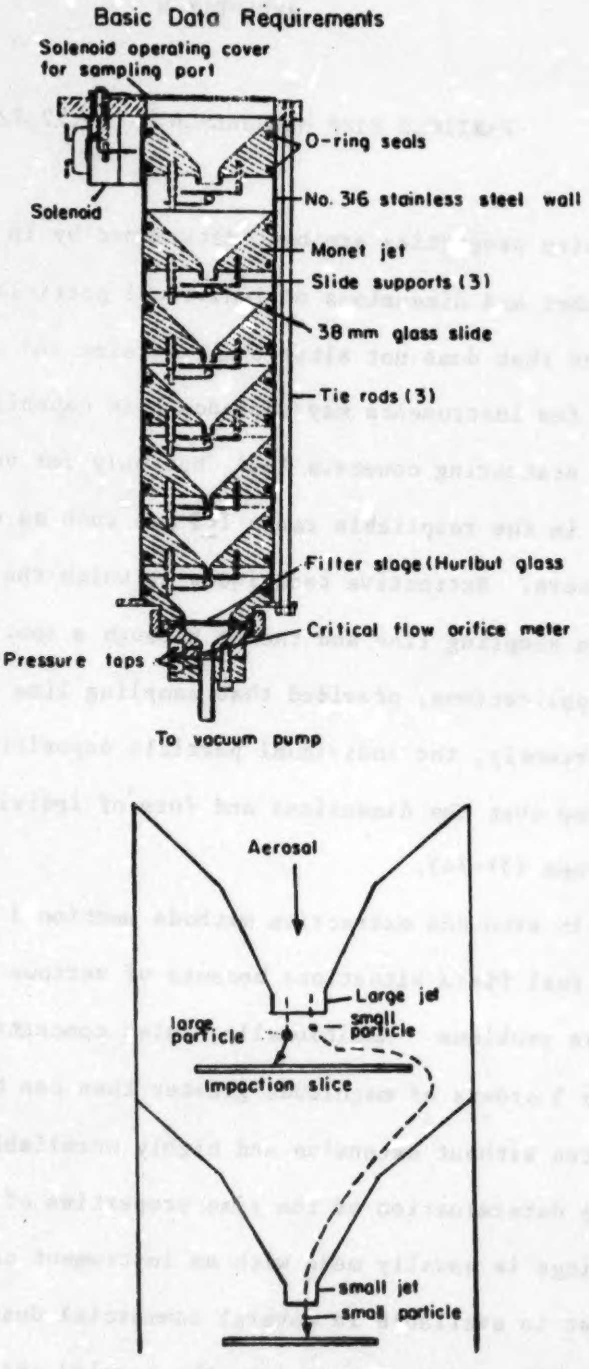
Basic Data Requirements
Solenoid operating cover for sampling port
O-ring seals
Solenoid
No. 316 stainless steel wall
Monet jet
Slide supports (3)
38 mm glass slide
Tie rods (3)
Filter stage (Hurlbut glass
Critical flow orifice meter
Pressure taps
To vacuum pump
Aerosol
Large jet
small particle
large particle
impaction slice
small jet
small particle

Figure B-1. Cascade impactor for particle size determination.

decreasing aperture size. Hence, the successive exit velocities increase as gas flows through the device (79). An impingement surface consisting of a high efficiency glass paper or an adhesive-coated glass or metal plate surface is placed before each jet (80). In accordance with the increasing jet velocities, a calculable fraction of the coarser particles approaching each stage impacts upon the collection stage, whereas the finer fraction is transported to the succeeding stage. The net result is a fractionation of the entering particulate material into several diameter categories from which the size distribution on a mass or weight basis can be ascertained for the entering dust. The smallest particle class of a cascade impactor is represented by the dust collected on a final high efficiency backup filter.

Because an impactor can be attached to the inlet end of a sampling probe, the possibility of sizing errors resulting from probe losses is reduced. In many field applications, sampling intervals of up to 30 minutes are possible (depending upon the dust concentration) before excessive dust is collected on the various impaction stages. Table B-1 shows a tabulation of typical sizing data used to construct a cumulative mass distribution curve for a coal fly ash (78). In normal practice, a characteristic diameter (usually that describing a spherical particle of unity density that is collected at 50 percent efficiency by that stage) is assigned to each stage based upon the manufacturer's and sometimes the user's calibration (77,78). These are the values shown in Table B-1 for the various stages.

TABLE B-1. TABULATED SIZING DATA, CASCADE IMPACTOR SAMPLING OF COAL FLY ASH AEROSOL

Stage No.	Characteristic[b] diameter	Mass percent on stage	Cumulative mass percent
Filter[a]	0.82	5.5	5.5
7	1.16	2.5	8.0
6	1.64	9.0	17.0
5	2.32	8.5	25.5
4	3.78	9.5	35.0
3	4.64	14.0	49.0
2	6.56	13.0	62.0
1	>6.56	38.0	100.0

[a] Estimated characteristic diameter, backup filter stage.

[b] Aerodynamic diameter for unit density spherical particle.

APPENDIX B

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*Reference numbers are those shown in main text.

APPENDIX C

BAGHOUSE AND FABRIC TERMINOLOGY

abrasion--flex: Cloth wear in a creased area by excessive or repeated bending.

abrasion--surface: Where the dirty cloth surface has been abraded by rubbing, scuffing, and erosion, in a more or less uniform fashion.

acetate: A manufactured fiber in which the fiber-forming substance is cellulose acetate.

acrylic: A synthetic polymerized fiber which contains at least 85 percent acrylonitrile.

air-to-cloth ratio: The ratio of gas volume to effective cloth area. Resulting units depict the filtration velocity.

backwash: A method of fabric cleaning in which direction of gas flow is reversed, accompanied by flexing of the fabric and breaking of the dust deposit; also called backpressure, repressure, collapse-clean.

bag: The customary form of a filter element. Also tube, stocking, etc. Can be unsupported (dust on inside) or used on the exterior of a grid support (dust on outside).

bag life: Number of years a bag will perform effectively. Usually 1 to 2 years.

bag reach: Number of parallel rows of bags on either side of interior walkway. (e.g., with a bag reach of two, an operator would only need to reach past one bag to service the most remote row).

bag tension: Force applied to a bag to hold it securely in position.

basket weave: An extension of plain weave.

batch cleaned: Usually refers to a process used in heat cleaning fiberglass cloth in roll form by exposing it to 500°-600°F, for prolonged periods to burn off the starches or binders.

beaming: Operation in which the yarn from several section beams is combined on the final loom beam.

bleed: Particles of dust or fumes that are able to leak through the bag.

blinding (blinded): The loading, or accumulation, of filter cake to the point where capacity rate is diminished. Also termed "plugged." Once enough material has built up, gas flow is severely restricted, and the bags have to be dry-cleaned or replaced.

broken twill: Modified twill weave where the diagonal twill line is shifted in a regular pattern.

bulked yarn: Multifilament yarn which has been processed by high pressure air passing through the yarn and relaxing it into gentle loops, bends, etc.

caking: Material crusted on a bag that cannot be removed by normal cleaning.

calendering: The application of either hot or cold pressure rolls to smooth or polish a fabric, thereby reducing the thickness of the cloth and decreasing air permeability.

canton flannel: Usually a twill weave fabric with the filling float heavily napped.

cap: Device that closes top of bag and is used to suspend bag from top of unit.

cell plate: Unit that holds the thimble.

cleaning cycle: Frequency and duration of dust cake removal.

chain weave: A 2/2 broken twill weave, arranged 2 threads right and 2 left.

cloth: In general, a pliant fabric--woven, knitted, felted, or otherwise formed of any textile fiber, wire, or other suitable material. Usually understood to mean a woven textile fabric.

cloth weight: Is usually expressed in ounces per square yard or ounces per square foot. However, cotton sateen is often specified at a certain number of linear yards per pound of designated width. For example, a 54" - 1.05 sateen contains 1.05 linear yards per pound in a 54" width.

cold spot: A point on an insulated baghouse where a continuous metallic heat transfer circuit through the insulation creates an uninsulated area.

compartment: Subdivision unit of a baghouse.

coronizing: A heat cleaning process for fiberglass fabric to burn off the starches (used in processing) usually at temperatures of 1000° to 1200°F for short duration.

cotton number: Staple yarns are generally sized on the cotton system. Example: an 18 singles yarn is of such size that 18 hanks (each hank contains 840 yards) weighs 1 pound.

cotton system: A system of yarn manufacturing for spinning cotton fiber into yarn, whereby the individual fibers are aligned parallel.

cover: A descriptive term for the appearance of plain woven goods. A "well covered" cloth is the opposite of an open, or "reedy" cloth.

creel: Device used as a yarn package rack to hold warp ends for a section beam.

crimp: The corrugations in a yarn from passing over and under other yarns at right angles.

crowfoot satin: A 3/1 broken twill arranged 2 threads right, then 2 threads left, etc. Also called 4 shaft satin, or broken crow weave.

cuff: Multithickness of cloth at ends of bag.

"DE" fiber: Diameter of most common glass fiber used in baghouses (0.00025 in.).

denier: The number, in grams, of a quantity of yarn, measuring 9000 meters in length. Example: A 200 denier yarn measuring 9000 meters weighs 200 grams. A 200/80 yarn indicates a 200 denier yarn composed of 80 filaments. Usually used for continuous multifilament yarns of silk, rayon, Orlon, Dacron, Dynel, Nylon, etc.

diaphragm valve: A compressed air-operated valve that is used to pulse-clean bags.

dimensional stability: Ability of the fabric to retain finished length and width, under stress, in hot or moist atmospheres.

doupe selvage: Two false selvages (fabric edge woven so that it will not unravel) woven in the cloth about 1/2-in. apart; useful for splitting the length of cloth in two.

drill weave: Same as twill except the diagonal twill line usually runs from lower right to upper left. A 2/1 LH twill, or 3/1 twill.

drop wires: Circuit breaking devices which stop loom or warper in the event of yarn breakage.

dust permeability: Defined as the mass of dust per unit area of filter medium (W) divided by the pressure loss (P) per unit velocity (V) through the medium; i.e., W V/P. In metric units (g)(m)/(N)(min). In English units (lb)/(in. water)(ft)(min). It is also the reciprocal of K_2 the "specific resistance coefficient". It should not be confused with the cloth (Frazier) permeability.

end: An individual yarn or cord; a warp yarn running along the length of the fabric.

end count: Same as warp count.

entering: Procedure in which warp yarns are drawn through drop wires, heddle eyes, and reed prior to going into loom.

envelope: A common form of filter element.

extensibility: The stretching characteristic of fabric under specified conditions of load, etc.

fabric: A planar structure produced by interlacing yarns, fibers, or filaments.
Knitted fabrics are produced by interlooping strands of yarns, etc.
Woven fabrics are produced by interlacing strands at more or less right angles.
Bonded fabrics are a web of fibers held together with a cementing medium which does not form a continuous sheet of adhesive material.
Felted fabrics are structures built by the interlocking action of the fibers themselves, without spinning, weaving, or knitting.

fiber: The fundamental unit comprising a textile raw material such as cotton, wool, etc.

filament: A continuous fiber.

fill: Crosswise threads woven by loom.

fill count: Number of fill threads per inch of cloth.

filling yarn: Yarns in a fabric running across the width of a fabric; i.e., at right angles to the warp.

filter cake: The accumulation of dust on a bag before cleaning. This cake assists in filtering the dust by the action of sieving.

filter drag: Pressure drop, in inches W.C. per cubic foot of air per minute, per square foot of filter media. Analogous to the resistance of an element in an electrical circuit. The ratio of filter pressure loss to filter velocity.

filter medium: The substrate support for the filter deposit; the fabric upon which the filter deposit is built.

filter velocity: The velocity, feet per minute, at which the air (gas) passes through the filter medium; the velocity of approach to the medium, the filter capacity rate, the air-to-cloth ratio.

filtration: The process of separating suspended solids from a liquid or gas usually by forcing a carrier gas or liquid through a porous medium.

filtration rate: The volume of air (gas), in cubic feet per minute, passing through 1 square foot of filter media. Also the air-to-cloth ratio.

finish: A treatment that imparts dimensional stability and provides protection to the woven fiber (e.g., silicone, graphite, Teflon, etc.)

flame retardant: A finish designed to reduce the combustibility of a fabric.

float: The position of a yarn that passes over two or more yarns passing in the opposite direction. Example: in standard cotton sateen, yarns "float" four, and pass under one; in other words, 4/1.

fluorocarbon: Fiber formed of long chain carbon molecules whose available bonds are saturated with fluorine.

fulled: A woven fabric treated to raise fiber ends (like napping) so that the thready, woven look is partially or completely obscured.

gabardine weave: A regular or "steep" twill, with higher warp than fill count.

garnett: Scrap fiber or fabric that has been torn severely and reduced once again to fiber, but of very short lentgh.

glass (fiberglass): A manufactured fiber in which the fiber forming substance is glass.

"grab": tensile: The tensile strength, in pounds per inch, of a textile sample cut 4 x 5 in. and torn apart lengthwise by two 1-in. square clamp jaws set 3 in. apart and pulled at a constant specified speed.

grading frame: Equipment which continuously runs a fabric over a well-lighted surface to enable an observer to view any defects.

greige cloth: Cloth as it comes off the loom or so-called "loom finish."

grid cloth: The cloth used in supporting the silver in making a supported, needled felt.

hand or handle: The "feel" of the cloth--as soft, harsh, smooth, rough, silken-like, boardy, etc.

harness: The frame used to raise or lower those warp yarns necessary to produce a specific weave while at the same time permitting the filling to be passed through by the shuttle.

head end: A piece of fabric taken from the end of a roll of cloth.

header: A pressurized pipe that contains the compressed-air supply for a pulse-type baghouse.

head set: A finishing process for a head end, in fabric form, to stabilize it against further shrinkage at predetermined temperatures.

heddle: Device in loom containing eyelets which yarn passes through while weaving.

herringbone weave: A type of "broken" (irregular) twill.

hydrophobic fibers: Fibers that do not readily absorb water.

interlacing: The points of contact between the warp and filling yarns in a fabric.

interstices: The openings between the interlacings of the warp and filling yarns; i.e., the voids.

K factor: The specific resistance of the dust cake, in inches water column per pound of dust per square foot of filter area per feet per minute filtering velocity. Also specific resistance coefficient, K_2, the reciprocal of dust permeability.

leno: A weave in which the adjacent warp yarns are twisted on either side of the interlacing filling yarn.

loom finish: Same as greige cloth.

mildew-resistant finish: An organic or inorganic finish to repel the growth of fungi on natural fibers.

modacrylic: A man-made fiber which contains less than 85 percent acrylonitrile (but at least 35 percent).

moleskin: A filling face fabric with a twill weave.

monofilament: A continuous fiber of sufficient size to serve as yarn in normal textile operations.

mullen burst: The pressure necessary to rupture a secured fabric specimen, usually expressed in pounds per square inch.

multifilament, multifil: Yarn composed of several filaments, which are continuous strands of fiber of indefinite length.

napping: A process to raise fiber or filament ends (for better coverage and more surface area) accomplished by passing the cloth over a large revolving cage or drum of small power-drive rolls covered with card clothing (similar to a wire brush).

needled felt: A felt made by the replacement of loose fiber in a systematic alignment, with barbed needles moving up and down, pushing and pulling the fibers to form an interlocking of adjacent fibers.

nonwoven felt: A felt made either by needling or matting of fibers or by compressing with a bonding agent for permanency.

nylon: A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polyamide having recurring amide groups.

olefin: A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight ethylene, propylene, or other olefin units.

oxford weave: Same as plain weave, except that two warp yarns weave as one warp yarn.

permeability, fabric: Measured on Frazier porosity meter, or Gurley permeometer, etc. Not to be confused with dust permeability. The ability of air (gas) to pass through the fabric, expressed in cubic feet of air per minute per square foot of fabric with a 0.5 in. W.C. pressure differential.

pick: An individual filling yarn running the width of a woven fabric at right angles to the warp. In England it is termed woof, or weft.

pick glass: A magnifying glass used in counting the warp and filling yarn in the fabric.

plain weave: Each warp yarn passing alternately over each filling yarn. The simplest weave, 1/1 construction. Also called taffeta weave.

plenum chamber: An air compartment maintained under positive or negative pressure, and connected to one or more ducts. A pressure equalizing chamber.

ply or plied yarn: Made by plying together two or more twisted yarns.

polyester: A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight of an ester of dihydric alcoholic and terephthalic acid.

porosity, fabric: Term often used interchangeably with permeability. Actually percentage of voids per unit volume--therefore, the term is improperly used where permeability is intended.

precoat: Material (i.e., fly ash, dolomite, etc.) added to air stream on initial baghouse start-up to aid in establishing filter cake on bags.

preshrink: Usually a hot aqueous immersion of the cloth to eliminate its tendency to shrink in further wet applications.

pressed felt: A type of felt manufactured by pressing fibers into a scrim.

pressure drop: Resistance of system to gas flow; pressure differential can be measured across fabric or across entire collector (flange-to-flange).

pressure (pulse) jet cleaning: A bag cleaning method where a transient burst or pulse of compressed air is introduced through a tube or nozzle attached to the top cap of a bag to remove dust from bag.

pressure system: Dust-laden air is pushed through the collector, fan on dirty side, creating positive pressure.

pulse cycle: The time interval between one pulsing of a row on bags and the next pulsing of the same row.

pulse interval: Time between pulsing one row of bags and pulsing the next row.

quill: Bobbin onto which filling yarn is wound.

ravel strip tensile: The tensile strength, in pounds per inch, of a 6-inch textile sample cut just over 1-inch wide (with yarns peeled off each side down to exactly 1-inch wide) pulled in two lengthwise between jaws set 3 inches apart and pulled at a constant specified speed.

rayon: A manufactured fiber composed of regenerated cellulose.

reed: A thin comb made of pressed steel wires between which warp ends are drawn after passing through the heddle eyes. the reed beats the filling picks into their respective places against the fill of the cloth.

reed marks: The indentations between 2, 3, or 4 ends, usually eliminated in finishing.

repeat: The number of threads in a weave before the weave repeats or starts over again. The number of ends and picks in the repeat may be equal or unequal, but in every case the repeat must be in a rectangular form.

reverse-air baghouse: A unit that is cleaned by flowing air in the opposite direction or backwards through the cloth (see backwash).

reverse jet cleaning: A cleaning method (Hershey) using a traveling ring traversing the exterior of the filter bag. High pressure air is blown backwards through the fabric through small holes or slots facing the cloth. This technique has been largely replaced by pulse jet cleaning in current practice.

rings: Metal bands sewn into a bag at various intervals to prevent bag collapse during cleaning.

sanforizing: A patented process where the cloth is "puckered" in the warp direction to eliminate shrinkage in laundering.

saran: any long-chain synthetic polymer composed of at least 85 percent vinylidene-chloride units.

sateen: cotton cloth made with a 4/1 satin weave, either as warp sateen or filling sateen.

satin weave: A fabric usually characterized by smoothness and luster. Generally made warp face with a great many more ends than picks. The surface consists almost entirely of warp (or filling) floats in construction 4/1 to 7/1. The intersection points do not fall in regular lines, but are shifted in a regular or irregular manner.

scour: A soap and hot water wash applied to "off loom" fabric.

scrim: A very loosely woven fabric through which felt is needled.

seeding: The application of a relatively coarse, dry dust to a bag before start-up, to provide an initial filter cake for immediate high efficiency and to protect bags from blinding (see precoat).

selvage: The binding lengthwise edge of a woven fabric.

service module: A compartment in a pulse-jet baghouse where valves, piping, wiring, and timers are located.

shaker baghouse: A unit using woven cloth bags where cleaning is accomplished by shaking the bags from the top.

shaking (cleaning): A common mechanical method of removing dust from filter elements. Backwashing or other supplemental methods are often used with shaking. Air-shaking is a bag cleaning means wherein bags are shaken in a random fashion by a variable velocity air stream rather than by mechanical devices.

shoddy: Reclaimed or reused wool.

shuttle: The device that holds the quill of filling yarn and carries it back and forth across the width of the fabric.

singeing: The burning off of the protruding hairs from the warp and filling yarns of the fabric.

singles: A protective coating applied to yarn to ensure safe handling; i.e., abrasion-resistance during weaving.

slashing: The method of applying size to a width of warp yarns on a continuous basis.

slippage: The movement or shifting of yarns in a fabric from their normal position.

slub: A heavy accumulation of fiber or lint carried on a yarn and interlocked during weaving.

sonic (sound): A fabric cleaning method using acoustic energy to vibrate the filter elements. Used alone, or as a supplement to shaking or backwash cleaning.

spun fabric: Fabric woven from staple (spun) fiber--same as staple.

staple fiber: Man-made fibers cut to specific length--1-1/2 in., 2 in., 2-1/4 in., etc.--natural fibers of a length characteristic of fiber type, animal fibers being the longest.

"S" twist: Direction of twist in yarn. Ascending: right to left configuration. (The yarn spirals conform in slope to the center portion of the letter "S".)

taffeta: Closely woven plain weave (1/1) fabrics with the warp yarns greatly outnumbering the filling yarns.

tenacity: Ultimate tensile strength of a fiber filament, yarn, etc. expressed in grams per denier (g.p.d.).

tensile strength: The ability of yarn or fabric to resist breaking by direct tension. Ultimate breaking strength in psi.

tenter frame: (pin tenter) A machine for drying cloth under tension. Tentering. Also called framing.

textile: That which is or may be woven. Comes from the Latin "texere," to weave. Hence, any kind of woven fabric.

textured yarn: Same as bulked yarn.

thimble: Flanged cylinder to which the bottom cuff of a bag is attached.

thread: Highly twisted and finished yarn used to fabricate bag seams.

thread count: The number of ends and picks per inch of woven cloth. For example, 64 x 60 (ends count first).

throw: Process of doubling of twisting fabrics into a yarn of the desired size and twist.

tow: A large number of filaments collected in a loose rope-like form, without definite twist.

T.P.I.: Twist per inch of yarn (turns per inch).

trumeter: A device used to accurately measure yardage passing a specific reference point.

tube sheet: The steel plate that bags and cages are suspended from in a pulse-type baghouse or to which the thimble sections are attached with mechanically shaken or reverse flow cleaned bags.

twill weave: Warp yarns floating over or under at least two consecutive picks from lower to upper right, with the point of intersection moving one yarn outward and upward or downward on succeeding picks, causing diagonal lines in the cloth.

twist: The number of complete spiral turns per inch in a yarn, in a right or left direction; i.e., "Z" or "S," respectively.

twist and ply frames: Machinery used to twist and ply glass yarns.

uniful: A device attached to the loom which automatically winds yarn onto quills from yarn packages and maintains a supply of quills for the shuttle.

vacuum system: Gas stream pulled through baghouse, fan on clean side, creating negative pressure inside collector.

velocity, approach: The velocity of air (gas), feet per minute, normal to the face of the filter medium.

warp: Yarns running lengthwise in woven goods.

warp beam: Large spool-like or barrel-like device on which the warp threads are wound.

warp count: Number of warp threads per inch of width.

warper: A machine for preparing and arranging the beamed yarns intended for the warp of a fabric.

warp sateen: The face of the cloth having the warp yarns floating over the filling yarns, with more warp yarns than filling yarns (per inch).

warp size: Chemicals applied to the warp yarn to improve strand integrity, strength, and smoothness in order to withstand the rigors of weaving.

weave: The pattern of weaving; i.e., plain, twill, satin, etc.

weft: Same as filling; the crosswise threads (yarns).

woof: Same as filling or weft.

woolen system: A "system" of yarn manufacturing for spinning wool fiber into yarn, usually more open and not aligned as parallel as the cotton system. This system is suited for shorter wools, various wastes, reclaimed wools, etc.

worsted system: A system of yarn manufacturing suited for medium and longer wools. Includes additional processing steps resulting in the most uniform yarn. The resulting yarn is compact and level.

woven felt: Predominantly a woven woolen fabric heavily fulled or shrunk, with the weave being completely hidden due to the entanglement of the woolen surface fibers.

yarn: Twisted fibers or filaments in a continuous strand suitable for weaving, etc. Ply yarn is formed by twisting two or more single yarns together. Ply yarns are in turn twisted together to form cord.

yarn size (denier, or count): A relative measure of fineness or coarseness of yarn. The smaller the number in spun yarns, the coarser the yarn. The higher the denier of a filament yarn, the coarser (heavier) the yarn.

"Z" twist: Direction of twist in yarn. Ascending left to right configuration. (The yarn spirals conform in slope to the center portion of the letter "Z").

INFORMATION SOURCES

PPG Industries, Inc. The Filtration Forum, Glossary of Terms Common to Baghouses Using Glass Fiber Cloth. Fiber Glass Division, The Gateway Center, Pittsburgh, PA 15222.

Reigel, S. A., and R. P. Bundy. "Why the Swing to Baghouses?" Power. 121:68, 1977.

Summit Filter Corporation. Glossary of Terms. 235 Broad Street, Summit, NJ 07901.

The McIlvaine Co., The Fabric Filter Manual, Chapter XIII, Sec. 1.1. Glossary of Fabric Filter Terms. 2796 Maria Ave., Northbrook, IL 60062.

APPENDIX D

SUPPLEMENTARY DATA
BAGHOUSES AND ACCESORIES

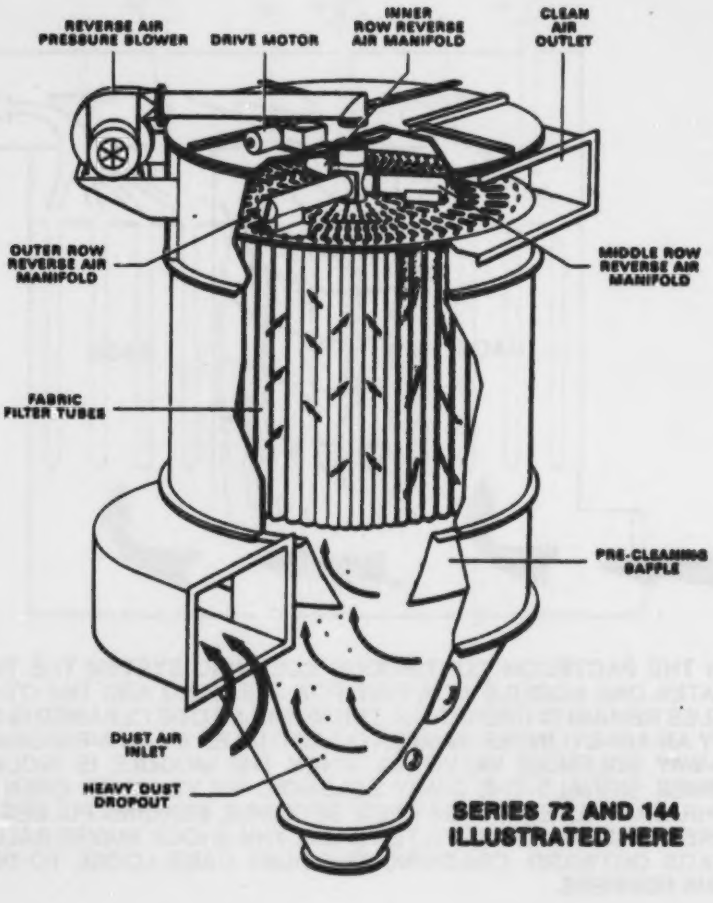
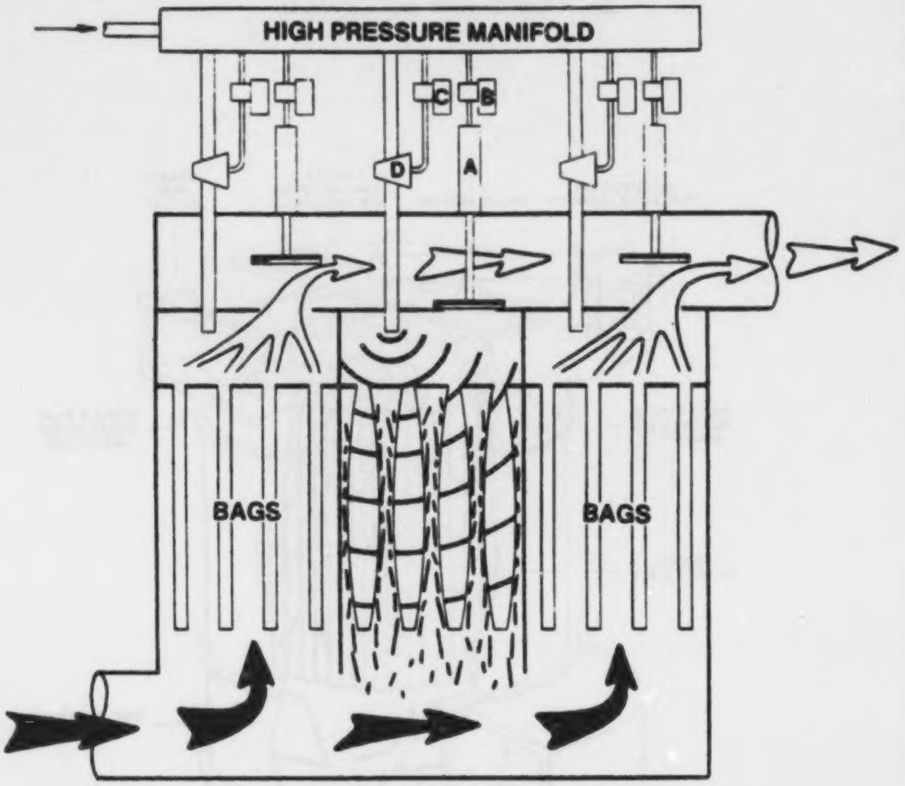

REVERSE AIR PRESSURE BLOWER
DRIVE MOTOR
INNER ROW REVERSE AIR MANIFOLD
CLEAN AIR OUTLET
OUTER ROW REVERSE AIR MANIFOLD
MIDDLE ROW REVERSE AIR MANIFOLD
FABRIC FILTER TUBES
PRE-CLEANING BAFFLE
DUST AIR INLET
HEAVY DUST DROPOUT
SERIES 72 AND 144 ILLUSTRATED HERE

Figure D-1. Cutaway drawing of an "RJ" reverse jet fabric filter--capacities from 3,000 to 76,500 acfm (courtesy of CEA--Carter-Day--excerpt from Bulletin No. RJ-2).

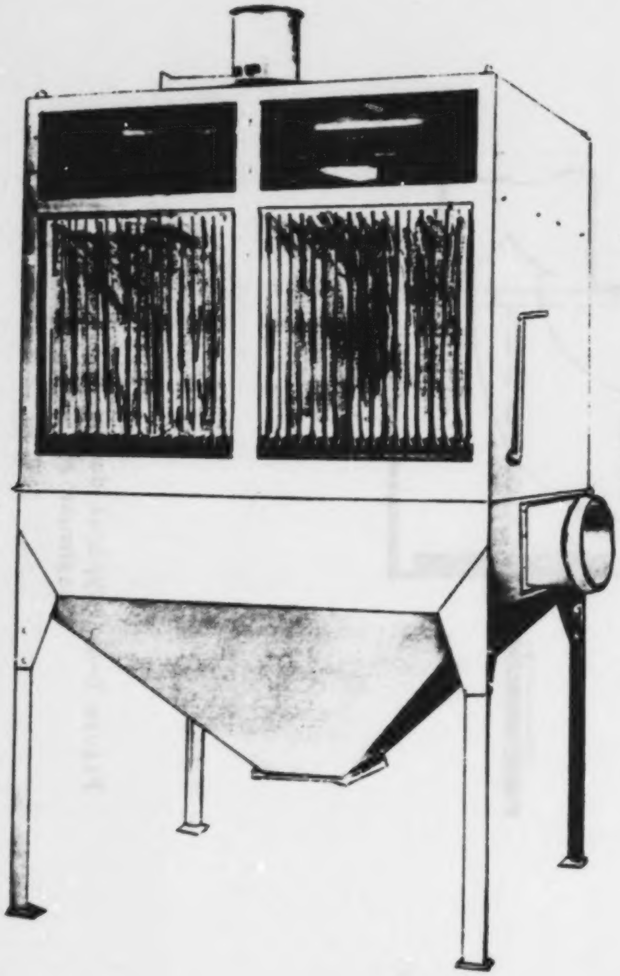


IN THE PACTECON CONTINUOUS CLEANING SYSTEM THE TIMER ISOLATES ONE MODULE AT A TIME FOR CLEANING AND THE OTHER MODULES REMAIN IN OPERATION. THE MODULE TO BE CLEANED IS ISOLATED BY AN AIR-CYLINDER DAMPER (A) ACTUATED BY AN AIR SIGNAL FROM A 3-WAY SOLENOID VALVE (B). WHEN THE MODULE IS ISOLATED THE TIMER SIGNALS THE 2-WAY SOLENOID VALVE (C) TO OPEN THE DIAPHRAGM VALVE (D) EVERY FEW SECONDS, SENDING PULSES OF HIGH-PRESSURE AIR TO THE FILTER BAGS. THE SHOCK WAVES BALLOON THE BAGS OUTWARD, CRACKING THE DUST CAKE LOOSE TO DROP INTO THE HOPPERS.

THE CUSTOMER CAN REGULATE THE NUMBER OF PULSES PER CYCLE, THE SIZE OF THE PULSE ("ON TIME") AND THE DELAY TIME BETWEEN CLEANING EACH MODULE.

THE WW SLY MANUFACTURING CO. CLEVELAND	PC AIR FLOW	P-1161

Figure D-2. Schematic of air flow in a "PC" Pactecon dust collector (courtesy of W. W. Sly Manufacturing Co.--excerpt from Instruction Book No. 693).



MULTIPLE RATING TABLES

MODEL	CFM	INLET VELOCITY (FPM)	EXTERNAL STATIC PRESSURE (INCHES W.G.)	PRESSURE DROP CLEAN FILTERS (INCHES W.G.)
130-219-5 1-8" dia. inlet 5 horsepower	1800	5140	7.75"	.25"
	2100	6000	7.00"	.28"
	2300	6570	6.50"	.31"
	2500	7140	6.00"	.35"
	2700	7710	5.70"	.38"
130-20-5-7½ 1-10" dia. inlet 7½ horsepower	2450	4500	12.00"	.37"
	2800	5140	11.00"	.42"
	3000	5500	10.30"	.46"
	3200	5670	9.60"	.50"
	3600	6600	8.00"	.60"
130-24-10 1-12" dia. inlet 10 horsepower	3400	4330	12.90"	.50"
	3600	4580	12.40"	.55"
	4000	5090	11.10"	.63"
	4400	5600	9.80"	.70"
	4800	6110	8.30"	.83"
130-24-15 1-12" dia. inlet 15 horsepower	4500	5725	9.40"	.80"
	4800	6110	8.30"	.85"
	5000	6360	7.60"	.90"
	5300	6700	6.40"	1.00"
	5600	7130	5.20"	1.10"

NOTES: Most dust and collected materials settle in hopper base. Fine dust which clings to the outside of cloth filters is easily dislodged by activating the manual filter shaker handle. An optional motor operated filter-shaker is also available.

Figure D-3. Series 130 cabinet cloth filter type self-contained dust collector (courtesy of the Torit Corp.--excerpt from Bulletin No. 1565).

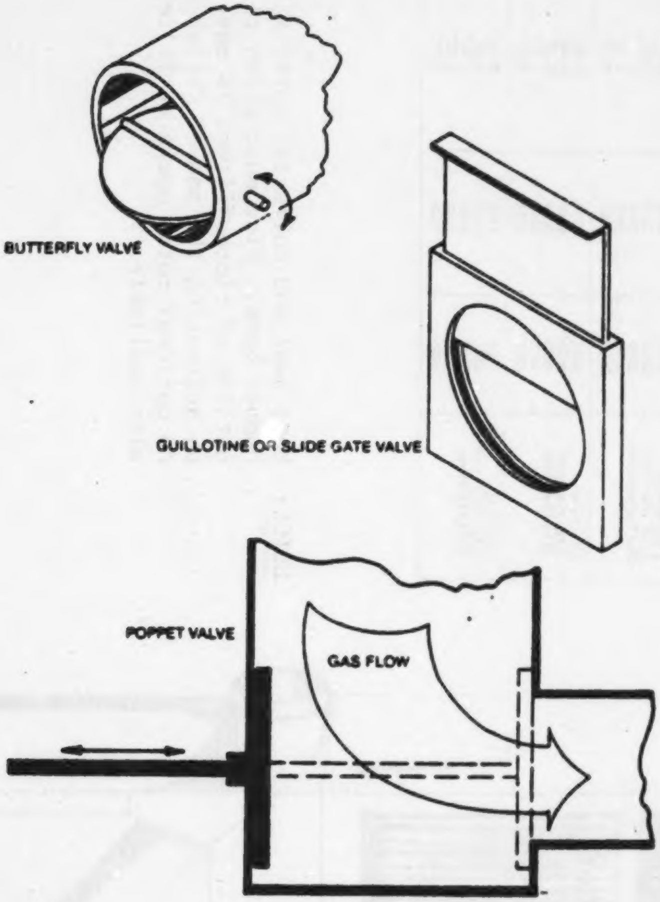
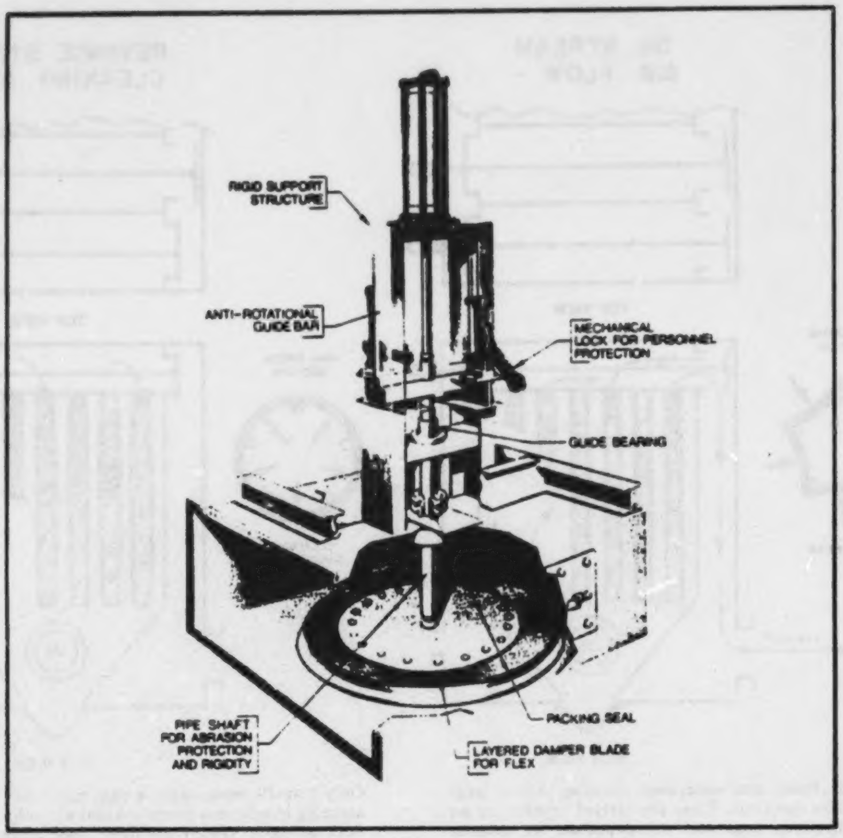

BUTTERFLY VALVE
GUILLOTINE OR SLIDE GATE VALVE
POPPET VALVE
GAS FLOW

Figure D-4. Typical damper valves used in baghouse systems.


RIGID SUPPORT STRUCTURE
ANTI-ROTATIONAL GUIDE BAR
MECHANICAL LOCK FOR PERSONNEL PROTECTION
GUIDE BEARING
PACKING SEAL
PIPE SHAFT FOR ABRASION PROTECTION AND RIGIDITY
LAYERED DAMPER BLADE FOR FLEX

POPPET DAMPERS

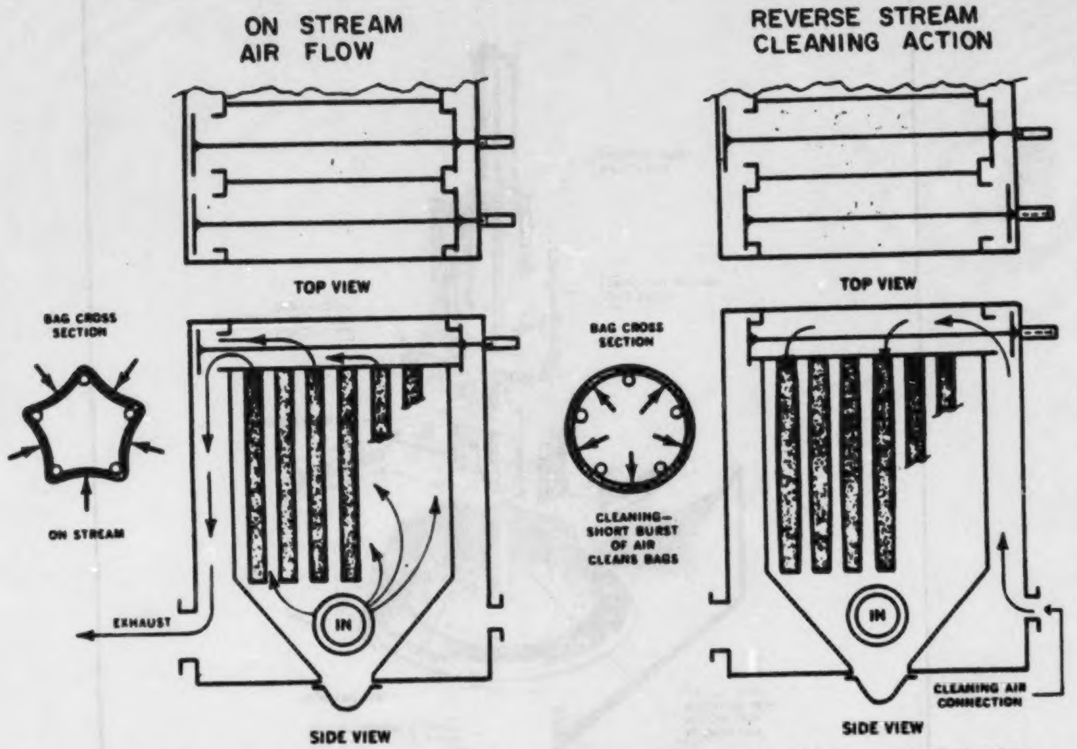
The AAF Poppet damper includes specific design features which result in quality beyond that normally found in the industry. The most common configuration is a vertical acting air cylinder-operated valve. The AAF design relies on a combination of rigidity, deflection and flatness for proper sealing. Most designs depend only upon deflection to accomplish sealing. Provisions are also included which eliminate blade rotation independent of the type of operator employed. Elimination of rotation ensures repeatable blade-seat matchup which is a necessary damper characteristic if it is to effect proper sealing.

AAF incorporates positive sealing at both ends of the damper operating stroke. This feature, in conjunction with the positioning and type of guide bearing employed, minimizes undesirable axial motion in the area of the damper shaft seal between the process air flow and atmosphere. Through experience and continued design improvement, AAF has developed a damper which requires very little seal maintenance and operates effectively when installed upright, inverted or horizontally.

When internal compartment inspection or bag maintenance is required, positive mechanical lockout is used to avoid accidental operation of the damper. The mechanical lockout system is double locking, using vise clamping and pinning.

A special patented feature included in AAF poppet damper application is the ''inching circuit.'' Until AAF developed this circuit, bag popping was frequently encountered when poppet dampers were employed. AAF's inching circuit provides control of damper movement with adjustable lift and dwell, which eliminates the need for the separate reinflation devices so completely that the old approach to soft reinflation is now considered obsolete.

Figure D-5. Poppet damper detail (courtesy of American Air Filter Company, Inc.).


ON STREAM
AIR FLOW
REVERSE STREAM
CLEANING ACTION
TOP VIEW
TOP VIEW
BAG CROSS SECTION
ON STREAM
BAG CROSS SECTION
CLEANING—SHORT BURST OF AIR CLEANS BAGS
IN
IN
EXHAUST
CLEANING AIR CONNECTION
SIDE VIEW
SIDE VIEW

Dirty air flows into expansion chamber where large particulates drop out. Fines are carried upward by air stream between bags and are deposited on exterior surface of fabric with filtered gas being discharged at the top of the bag into the bag manifolds. The clean air passes over the top of the unit down through the outer double wall of the collector, acting as insulation, into an exhaust plenum at the bottom of the collector. This plenum insulates the hopper and acts as a duct to fan connection at a level where fan is normally located. This keeps the external duct work and supporting members at a bare minimum.

Only a small percentage of bags are cleaned at a time, assuring continuous operation and virtually eliminating fluctuations in system gas flow. Upon a signal from the control box, two rows of bags (28 bags) are isolated from the exhaust plenum by means of a pneumatically operated damper.

The damper permits a sudden, short burst of clean air from the reverse air plenum to enter the filter bags resulting in a controlled "snap action" of the bags which breaks the dust cake off the outside of the bags. The damper then returns to its normal position, permitting clean air to flow up the bags and out into the exhaust plenum. The entire cleaning process for two rows of bags is only seconds in duration.

At controlled intervals, each subsequent two rows of bags is isolated from the exhaust plenum by means of the control system and cleaned in the manner described above. The entire cleaning process is continuously repeated during the operation of the collector. The dust cake drops to the bottom of the collector where it is collected and discharged by means of the screw conveyor.

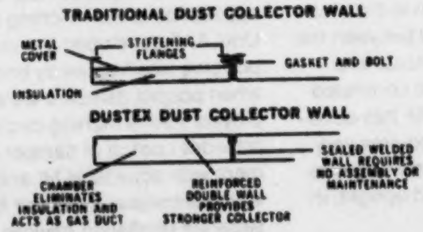

TRADITIONAL DUST COLLECTOR WALL
METAL COVER
STIFFENING FLANGES
GASKET AND BOLT
INSULATION
DUSTEX DUST COLLECTOR WALL
SEALED WELDED WALL REQUIRES NO ASSEMBLY OR MAINTENANCE
CHAMBER ELIMINATES INSULATION AND ACTS AS GAS DUCT
REINFORCED DOUBLE WALL PROVIDES STRONGER COLLECTOR

Figure D-6. Schematic diagrams of filtering and cleaning operation modes in a type DW reverse pulse collector (courtesy of American Precision Industries, Inc., Dustex Div.--excerpt from Bulletin No. 571.)

APPENDIX E

U.S. BAGHOUSE MANUFACTURERS[a]

Abart Engineering Ltd.
Ace Engineering Company
Aerex Corporation
Aerodyne Development Corporation
AeroPulse, Inc.
Aerosols Control Corporation
Aget Manufacturing Company
Allis-Chalmers Corporation
American Air Filter Co., Inc.[b]
Andersen 2000 Inc.
Babcock & Wilcox Company, The
BACT Engineering, Inc.
Bahco Systems, Inc.
B.B. Barefoot & Associates, Inc.
Belco Pollution Control Corporation[b]
Beltran Associates, Inc.
Bionomic Industries
Black Clawson, Inc.
Buell Division, General Electric
Buffalo Forge Company[b]
Buhler-Miag, Inc.
Cadre Corporation, The
Carborundum Environmental Systems[b]
  Division,
  Flakt, Inc.
CEA Carter-Day Company
CEA Combustion, Inc.
CEA Simon-Day Ltd.
C-E Air Preheater
  Sub. of Combustion Engineering Inc.
C-E Raymond/Bartlett-Snow,
  A Division of Combustion
  Engineering, Inc.
Continental Air Filters Co.
Continental Air Products, Inc.
Crystal-X Corporation
DCE Vokes, Inc.
Dust Control Company
Dustex Division,
  American Precision Industries, Inc.
Dust Suppression Systems, Inc.
Eastern Control Systems, Inc.
Ecolaire Environmental Company
Fisher-Klosterman, Inc.[b]
Flakt Canada, Ltd.
Flakt, Inc.
Flex-Kleen Corporation
Fuller Company,[b]
  Dracco Products
General Electric Environmental
  Systems, Inc.
General Resource Corp.
Griffin Environmental Company, Inc.
Industrial Clean Air
Interel Corporation
Jazco Corporation
Johnson-March Corporation, The
Kleissler Company, G.A.
Lear Siegler, Inc.
  Environmental Technology Division
MAC Equipment Inc.
MacDonald Steel (1976) Ltd.
Mahon Industrial Corporation,
  Subsidiary of Pullman Inc.
McInnis Equipment Limited
Mikropul Corporation,
  U.S. Filter Corporation[b]
Mine Safety Appliances Co.
Neptune AirPol Inc.
Niro Atomizer Inc.
Norblo Division, Envirotech Corporation
Peabody Engineering Corporation[b]
Research-Cottrell, Inc.[b]
Rolfes Comapny, George A.
Ruemelin Manufacturing Co.
Sly Manufacturing Co., The W.W.
Smith Environmental Corp.
Standard Havens Inc.
Steelcraft Corporation
Sternvent Company, Inc.
Tag Construction Company
Terrell Machine Company
Thyssen Environmental Systems, Inc.
Torit Corporation, The[b]
United McGill Corporation,
  Dust Collector Division

U.S. BAGHOUSE MANUFACTURERS[a] (Cont'd)

Eltron Manufacturing, Inc.
Emtrol Emission Control Systems
Environmental Elements Corporation
  Subsidiary of Koppers Company, Inc.
Enviro-Systems & Research, Inc.
ESSTEE Manufacturing Co., Inc.
Fabric Filters Corporation
Ferro Tech Inc.

USF Environmental Systems Corp.
Western Precipitation Division of Joy[b]
  Manufacturing Co.
Wheelabrator Frye, Inc.
  Air Pollution Control Division[b]
Wiedenmann & Son, Inc., W.C.
Young Industries, Inc. The
Zurn Industries, Inc.,[b]
  Air Systems Division

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[a] From APCA Directory and Resource Book (1982-1983)
Air Pollution Control Association, P.O. Box 2861
Pittsburgh, PA 15230

[b] Member of the Industrial Gas Cleaning Institute (IGCI)
Suite 304, 700 N Fairfax St., Alexandria, VA 22314

APPENDIX F

FABRIC FILTER MODEL
(CAPSULE DESCRIPTION)

BACKGROUND

A comprehensive treatment of the development and design of a new fabric filtration model, structured specifically so that enforcement engineers can assess the fly ash control capabilities of filter systems used at coal burning facilities, has been discussed extensively in the literature (1,46,48,100,121, 173,174). To facilitate and encourage model application,* a condensed Users Guide was prepared (174) to demonstrate the ease with which the model could be used by any engineer possessing a rudimentary knowledge of the fabric filtration process. The following excerpts highlight the basic model function by describing a typical field application.

EXAMPLE OF MODEL APPLICATION

An electric utility operates two, coal-burning steam-electric plants, the first of which (Plant A) now uses a pressure-controlled baghouse to prevent particulate (fly ash) emissions. It has been proposed that a continuously cleaned fabric filter system be installed at the second plant (Plant B). Both the utility operator and the local emission enforcement groups would like to determine whether operation of the filter system in accordance with the input data shown in Table F-1 (some of which is based on Plant A experience) will satisfy local emission requirements while maintaining average system pressure drop levels within the exhaust capacity range of the induced draft fans. For present purposes, it is assumed that operation at an efficiency of 99.5 percent (equivalent to 0.5 percent penetration) and an average pressure drop of 1750 N/m^2 (7 in. water) indicates acceptable performance.

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*Model based on Fortran language and designed initially for compatibility with an IBM 360 computer or equivalent system via card deck or tape access.

Design and operating data appearing in Table F-1 for the proposed "second" plant baghouse represent a composite of information received from both utility personnel and the dust collector manufacturer. It is also assumed that previous measurements of uncontrolled mass emission rates and fly ash size parameters at both plants are available, as well as estimates for the terms K_2, S_E, and W_R based upon prior tests performed at Plant A.

The data shown in Table F-1 are sufficient to carry out the predictive modeling operation. After converting the terms to their metric equivalents, Table F-2 (noting that raw field data are frequently supplied in English units), the data inputs are ready for punchcarding or terminal entry as shown in the card listings of Figure F-1.

Card 1 contains the title that will appear on the program output. Note that on Card 2 the time between cleaning cycles, Item 4, and the limiting pressure, Item 5, have been left blank because a continuous cleaning system has been chosen. The reverse flow velocity, Item 6, Card 2, is calculated from the total reverse flow rate (30,000 acfm) and the cloth area per compartment (200,000 $ft^2/30$) as 4.5 ft/min or 1.37 m/min. The average face velocity, Item 9, Card 3, is computed from the indicated value for the total

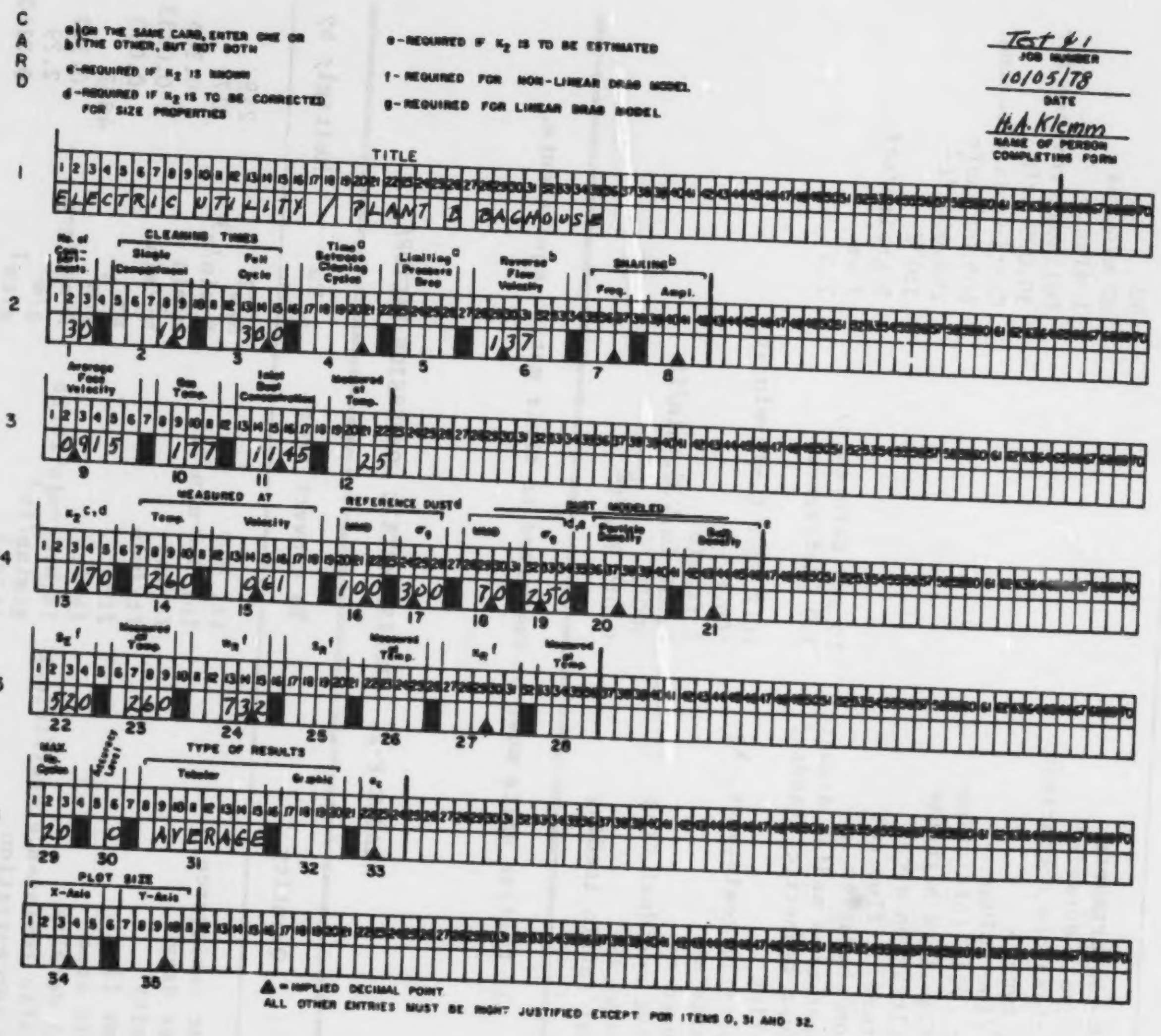
TABLE F-1. AVAILABLE INPUT DATA FOR MODELING BAGHOUSE PERFORMANCE AT ELECTRIC UTILITY, PLANT B

	Plant A	Plant B
Number of compartments		30
Cleaning cycle duration		30 minutes
Time to clean one compartment		1 minute
Cleaning type		Collapse/reverse air
Reverse flow volume		30,000 acfm
Cleaning cycle initiation		Continuous cleaning
Volume flow into baghouse		600,000 acfm
Total filtration area		200,000 ft^2
Temperature of flue gas		350°F
Inlet concentration		5 grains/scf
Inlet dust mass median diameter	10 μm (Reference)	7 μm
Inlet dust geometric standard deviation	3.0 (Reference)	2.5
Dust specific resistance, K_2	10.2 in.W.C.-ft-min/lb	
Measured at	500°F	
Measured at	2 ft/min	
Effective residual drag	0.636 in.W.C.-min/ft	
Measured at	500°F	
Residual fabric loading	0.015 lb/ft^2	

Note: All English units must be converted to their metric equivalents.

TABLE F-2. ENGLISH/METRIC CONVERSION FACTORS

Quantity	To convert from	To	Multiply by
Filter resistance	in. H_2O	N/m^2	249
Filter drag	in. H_2O-min/ft	N-min/m^3	817
Velocity	ft/min	m/min	0.305
Volume flow	ft^3/min	m^3/min	0.0283
Fabric area	ft^2	m^2	0.093
Areal density	lb/ft^2	g/m^2	4882
Specific resistance coefficient	in.W.C.-min-ft/lb	N-min/g-m	0.167
Dust concentration	grains/ft^3	g/m^3	2.29
Density	lb/ft^3	g/cm^3	0.0160


CARD

a) ON THE SAME CARD, ENTER ONE OR
b) THE OTHER, BUT NOT BOTH
c-REQUIRED IF K_2 IS KNOWN
d-REQUIRED IF K_2 IS TO BE CORRECTED FOR SIZE PROPERTIES
e-REQUIRED IF K_2 IS TO BE ESTIMATED
f-REQUIRED FOR NON-LINEAR DRAG MODEL
g-REQUIRED FOR LINEAR DRAG MODEL

JOB NUMBER: Test #1
DATE: 10/05/78
NAME OF PERSON COMPLETING FORM: H.A. Klemm

1 TITLE: ELECTRIC UTILITY / PLANT B BAGHOUSE

2
- No. of Compartments (1): 30
- CLEANING TIMES, Single Compartment (2): 10
- CLEANING TIMES, Full Cycle (3): 300
- Time Between Cleaning Cycles[a] (4):
- Limiting Pressure Drop[a] (5):
- Reverse Flow Velocity[b] (6): 137
- SHAKING[b], Freq. (7):
- SHAKING[b], Ampl. (8):

3
- Average Face Velocity (9): 0915
- Gas Temp. (10): 177
- Inlet Dust Concentration (11): 1145
- Measured at Temp. (12): 25

4
- K_2[c,d] (13): 170
- MEASURED AT Temp. (14): 260
- MEASURED AT Velocity (15): 061
- REFERENCE DUST[d] MMD (16): 100
- REFERENCE DUST[d] σ_g (17): 300
- DUST MODELED[d,e] MMD (18): 70
- DUST MODELED[d,e] σ_g (19): 250
- Particle Density (20):
- Bulk Density (21):

5
- S_E[f] (22): 520
- Measured at Temp. (23): 260
- W_R[f] (24): 732
- S_R[f] (25):
- Measured at Temp. (26):
- K_R[f] (27):
- Measured at Temp. (28):

6
- MAX. No. Cycles (29): 20
- Accuracy Level (30): 0
- TYPE OF RESULTS, Tabular (31): AVERAGE
- TYPE OF RESULTS, Graphic (32):
- a_c (33):

7
- PLOT SIZE, X-Axis (34):
- PLOT SIZE, Y-Axis (35):

▲ = IMPLIED DECIMAL POINT
ALL OTHER ENTRIES MUST BE RIGHT JUSTIFIED EXCEPT FOR ITEMS 0, 31 AND 32.

Figure F-1. Fabric filter model - data input form prepared from Table F-1 input data.

gas flow (600,000 acfm) and the total fabric area (200,000 ft^2) as 3.0 ft/min (0.915 m/min). Inlet concentration is reported at ambient temperature, 25°C, the value entered for Item 12, Card 3.

The data available from Plant A allow for adjustment of the measured K_2 value at Plant A for the size properties of the dust at Plant B. Thus K_2, the temperature and face velocity at which it was measured, and the size properties of the two dusts are entered as shown on Card 4.

Twenty cycles are considered sufficient to complete the simulation and achieve steady state conditions (see Card 6). Similarly, an accuracy level of zero is considered acceptable for the first trial. Because the utility personnel and the enforcement agency are concerned mainly with average emission rates and average pressure drop, AVERAGE results are requested. Since no plotting is desired, Item 32, Card 7 has been left blank.

If the results of the simulation had indicated emission levels close to, but greater than, the allowable level, the simulation could have been rerun with an accuracy level of 1. If convergence had not been reached within 20 cycles, a value of 40, for example, might have been entered provided that the costs for added computer time were acceptable.

In Table F-3, the actual computer printout provided for the input data and the coded instructions of Figure F-1 have been arranged in a convenient tabulation showing each of four separate printout sheets. Printout No. 1 shows the actual summarized input data as entered into the program so that the user can check the data for errors or omissions. Printout No. 2 instructs the user via the statement "There are no errors in the input data" that the modeling program will be executed as requested. Printout No. 3 provides a listing of those parameters whose values are computed or corrected by the

TABLE F-3. SAMPLES OF TABULAR PRINTOUT FOR EXAMPLE OF MODEL APPLICATION

PRINTOUT NO. 1

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***************************************************************************

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

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AN ELECTRIC UTILITY / PLANT B BAGHOUSE

BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              30
     COMPARTMENT CLEANING TIME            1.0          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                 30.0          MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY                1.3725       M/MIN


OPERATING DATA
     AVERAGE FACE VELOCITY                0.9150       M/MIN
     GAS TEMPERATURE                    177.           DEGREES CENTIGRADE
     INLET DUST CONCENTRATION            11.45         G/M3
          MEASURED AT                    25.           DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2              1.70         N-MIN/G-M
          MEASURED AT                   260.           DEGREES CENTIGRADE
                                          0.6100       M/MIN
                       MMD1              10.0          MICRONS       -STANDARD DEVIATION 3.00
          CORRECTED TO MMD2               7.0          MICRONS       -STANDARD DEVIATION 2.50

     EFFECTIVE RESIDUAL DRAG, SE        520.           N-MIN/M3
          MEASURED AT                   260.           DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                73.2          G/M2

SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED       20
     ACCURACY LEVEL                     0
     TYPE OF RESULTS REQUESTED          AVERAGE /
```

PRINTOUT NO. 2

```
DIAGNOSTIC MESSAGES


THERE ARE NO ERRORS IN THE INPUT DATA
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program, such as a_c and K_2. Again, inspection of these data by the model user allows him to determine the reasonableness of the indicated values. Finally, the AVERAGE data shown in Printout No. 4 indicate that both the pressure drop and penetration expectations for the filter system (1750 N/m^2 and 0.5 percent) should be realized. In addition, Printout No. 4 also indicates that 10 cycles, rather than the 20 requested on the data input form, were sufficient to define steady state operating conditions.

APPENDIX F*

REFERENCES

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100. Dennis, R., H. A. Klemm, and W. Battye. Fabric Filter Model Sensitivity Analysis. EPA-600/7-79-043c, 1979.

107. Dennis, R., and J. E. Wilder. Fabric Filter Cleaning Studies. EPA-650/2-75-009 (NTIS No. PB-240-372/3G1), January 1975.

121. Dennis, R., R. W. Cass, and R. R. Hall. Dust Dislodgement From Woven Fabrics Versus Filter Performance. J Air Poll. Control Assoc. 48(1), 47, 1978.

173. Dennis, R., and N. F. Surprenant. Particulate Control Highlights: Research on Fabric Filtration Technology. EPA-600/8-78-005d. (NTIS PB-285-393/5BE), June, 1978.

174. Dennis, R., and H. A. Klemm, "Fabric Filter Model Format Change," Volume I Detailed Technical Report, Volume II User's Guide. EPA-600/7-79-043a (NTIS PB-293-551/8BE). EPA-600/7-79-043b (NTIS PB-294-042/7BE), February, 1979.

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*Reference numbers are those shown in main text.